INSTRUCTIONS

AND

Manual of Radio Frequency Measurements

FOR Q-METERS

TYPE 100-A
TYPE 160-A
TYPE 170-A

[redacted]

Boonton Radio Corporation

BOONTON, NEW JERSEY
U. S. A.

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FOREWORD

THE Manual of Radio Frequency Measurements is written principally around the types 100-A and 160-A Q-Meters. The same general measurement technique described in the Manual is also applicable to the type 170-A. Special precautions associated with measurements at very high frequencies are contained in the operating instructions for the type 170-A Q-Meter.

Attention is called to the fact that the frequency ranges, tuning capacitance ranges and Q Voltmeter calibrations, and also the accuracy and frequency limitations, of the three instruments are different. Also that the ranges of values of components that can be measured with the type 170-A Q-Meter are quite different from the values measurable with the types 100-A and 160-A Q-Meters.

Occasional reference is made in the text to the "Q Range Meter," also to the "250 and 500 lines" on this meter. These references apply to the Q Range Meter in the type 100-A Q-Meter. In the types 160-A and 170-A Q-Meters the "Q Range Meter" has been replaced by the "Multiply Q By" Meter and the equivalent settings for this meter are the "x1 and x2" lines, respectively.

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PART ONE

MANUAL OF RADIO FREQUENCY MEASUREMENTS FOR THE THE Q-METER

PART TWO

Instructions for Installation, Operation and Maintenance, Circuit Diagrams, Lists of Parts

WARRANTY

THE Manufacturer warrants each new instrument manufactured and sold by it to be free from defects in material, workmanship, and design. Under this warranty our obligation is limited to repairing or replacing any instrument or any part proved to be defective by our inspection, within one year after sale to the original purchaser.

This warranty shall not apply to tubes or any instrument which shall have been repaired or altered outside of our plant in any way so as, in the judgment of the Manufacturer, to affect its stability or reliability, nor which has been subject to misuse, negligence or accident.

The Manufacturer reserves the right to make changes in design or add improvements to the instruments manufactured by it at any time without incurring any obligation to install same in instruments previously purchased.

All instruments returned under this warranty should be sent to the Manufacturer with charges prepaid. After repairs have been completed the instrument will be returned all charges prepaid by the Manufacturer.

BOONTON RADIO CORPORATION
BOONTON, NEW JERSEY
U. S. A.

Every effort has been made to avoid mistakes in preparing the material for this book. It will be greatly appreciated if any errors that have inadvertently been included in this issue are brought to the attention of Boonton Radio Corporation.

PART ONE

SIGNIFICANCE OF THE FACTOR Q

The symbol Q is commonly used to designate the ratio of reactance to resistance of a coil ($Q = 2\pi fL/R$), of a condenser ($Q = 1/2\pi fCR$), or other circuit elements having two accessible terminals. This factor is of importance in circuit design since it constitutes a "figure of merit" for the reactive element in question.

In circuit design the first things arrived at usually are the values of the reactors, which are generally determined by frequency considerations, such as tuning range, cut-off frequencies and so forth. The engineer is then confronted with the practical problem of realizing their values of reactance physically. In the solution of this problem one of the most important considerations is the amount of loss, or resistance, that can be tolerated, or more accurately, to balance the cost of reducing the resistance against the improvement in circuit performance which is brought about thereby. Since Q by definition expresses the ratio of a given reactance to its resistance it can be advantageously employed for the purpose of quantitatively comparing various reactors. In a simple resonant circuit with series impressed voltage, the ratio between the voltage across the coil or condenser to the impressed voltage ("voltage step-up") is directly proportional to Q. In the case of more complicated circuits the performance also depends upon Q but naturally not in such a simple fashion. In general it can be stated that the higher the Q's of the reactive elements the better will be the performance of the circuit. An example of the application of this principle in a complicated circuit is found in the case of a filter, where it is known that high Q's in the reactors improve the transmission in the pass band and sharpen the cut-off.

These remarks on the significance of Q in circuit design may be illustrated by a few simple examples.

Consider first the case of a simple resonant circuit comprising in series an inductor of inductance L and resistance R_L, and a condenser of capacitance C and resistance R_C. If a voltage E be introduced into the circuit the voltage across the inductor, or condenser, at resonance will be (very closely):

$$E_L = \frac{E\omega L}{R_C + R_L} \qquad (1)$$

Denoting the Q's of the coil and condenser by Q_L, ($\omega L/R$) and Q_C, ($1/\omega CR_C$) repectively, (1) may be written:

$$E_L = \frac{E}{\frac{1}{Q_L} + \frac{1}{Q_C}} = E\,\frac{Q_L\,Q_C}{Q_L + Q_C} \qquad (2)$$

In well designed radio circuits the losses in the condenser will be negligible compared with the losses in the coil so that Q_C will be much greater than Q_L. In this case (2) becomes

$$E_L = EQ_L \qquad (3)$$

or in other words the voltage step-up is directly proportional to the Q of the coil.

In circuit combinations which are more complicated than the simple example considered above Q is also of significance, but naturally not so directly. Consider, for example, two coupled circuits, the first comprising inductance L_1, capacitance C_1, and resistance R_1 in series; the second comprising L_2, C_2, and R_2 in series. If a voltage E be introduced into circuit 1, with both circuits in resonance, the voltage across the coil (or condenser) in the second circuit for optimum coupling will be:

$$E_2 = E\,\frac{\omega L_2}{2\sqrt{R_1 R_2}} \qquad (4)$$

$$= \frac{E\,Q_2}{2}\sqrt{\frac{R_2}{R_1}} \qquad (5)$$

where Q_2 represents the Q of circuit 2. In this case we see that so far as circuit 2 is concerned the step-up varies as $\omega L_2/\sqrt{R_2}$ instead of as $\omega L_2/R_2 = Q_2$ and Q does not directly determine the result. However, the same variations of the factors ω, L and R which would increase Q would undoubtedly increase the step-up also, even though this is not directly proportional to Q.

Consider a third case of practical interest, an inductor and condenser in parallel as a coupling element in a tube of the screen-grid type. With such tubes the plate resistance is generally so high compared with the anti-resonant impedance of the coupling circuit that the gain is approximately proportional to the coupling element impedance. In the case considered this impedance will be, at anti-resonance, a pure resistance of the value

$$\frac{\omega^2 L^2}{R} = Q\omega L = Q^2 R \qquad (6)$$

Here again the overall gain will not be directly proportional to Q but to the product of Q and ωL; however, if the value of inductance be fixed by other considerations the gain will be proportional to Q.

We see that although the overall transmission is not always directly proportional to Q, Q always enters as a positive factor; in no case does the transmission depend inversely on Q. We can sum up this discussion by saying that Q is a measure of the "merit" of the reactive element and that in general the higher the Q's of the reactive elements the better will be the performance of the circuit.

Other quantities, closely related to Q, which have been proposed or used to represent the merit of reactive elements may be noted here, as follows:

DISSIPATION FACTOR–POWER RATIO –η. (Sometimes denoted by *d*.)

This is defined as the ratio of resistance to reactance of an impedance, i.e.,

$$\eta = \frac{R}{X} = \frac{R}{\omega L} = R\omega C = \frac{1}{Q} \qquad (7)$$

While convenient for mathematical work it is less desirable than Q descriptively because it becomes smaller as the reactor gets better.

POWER FACTOR.

Power factor is the ratio of resistance to impedance and is equal to the cosine of the phase angle θ, i.e.,

$$\text{Power factor} = \cos\theta = \frac{R}{\sqrt{R^2 + X^2}} \qquad (8)$$

The reciprocal of this quantity approaches Q as Q increases. When Q is greater than 10 the power factor is practically equal to the reciprocal of Q, the difference being less than 1 per cent. Thus, for impedances having a Q over 10, the following relation is correct to better than 1%, i.e.,

$$\text{Power factor} = \cos\theta = \frac{1}{Q} \qquad (9)$$

PHASE ANGLE–θ.

The phase angle of an impedance is the phase angle between the current through the impedance and the voltage across the impedance. It is the angle, in radians or degrees, whose cotangent is equal to R/X, i.e.,

$$\cot\theta = \frac{R}{X} = \frac{R}{\omega L} = R\omega C = \frac{1}{Q} \qquad (10)$$

PHASE DIFFERENCE–ψ.

This is the complement of the phase angle θ and is the angle whose tangent is equal to R/X, i.e.,

$$\tan\psi = \frac{R}{X} = \frac{R}{\omega L} = R\omega C = \frac{1}{Q} \qquad (11)$$

THEORY OF THE METHOD OF MEASUREMENT

The theory of the method of measurement employed in the Type 160-A Q-Meter may be explained with the aid of a schematic diagram of the fundamental circuit of the instrument.

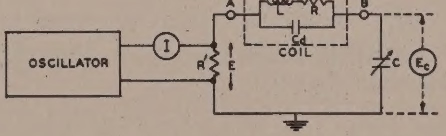


Fig. 1

The oscillator furnishes a current, measured by means of the ammeter, which flows through the special resistor R'. This resistance R' (0.04 ohm) will usually be small compared with the other resistances in the circuit and can be neglected, or, if the circuit resistance is especially low, corrected for. A known voltage E is thus introduced into the series circuit comprising the variable condenser C and the inductive reactor under measurement, connected across the terminals AB. The condenser C is contained in the instrument and its effective resistance is negligible.

By way of illustration we shall consider the measurement of the Q of a coil having inductance L, resistance R, and distributed capacitance C_d, as shown connected to the terminals AB.

In general, any two-terminal inductive reactor which might be connected across AB can be represented by an effective series inductance L_e and an effective series resistance R_e. At resonance the condenser reactance will balance the effective series reactance between A and B and the current will be (neglecting R′):

$$I = \frac{E}{R_e} \qquad (12)$$

The voltage E_c across the condenser C is measured by means of a voltmeter having negligible power consumption. Then:

$$\frac{E_c}{E} = Q_e = \frac{1}{\omega C R_e} \qquad (13)$$

At resonance $1/\omega C = \omega L_e$, hence:

$$\frac{E_c}{E} = Q_e = \frac{\omega L_e}{R_e} \qquad (14)$$

This is defined as the effective Q of the coil or other impedance connected to AB.

The method of measurement thus yields the "effective Q". This differs somewhat from the true Q, which is defined by:

$$Q = \frac{\omega L}{R} \qquad (15)$$

A detailed analysis shows that in the case of a coil, the difference between the true Q and effective Q depends on the distributed capacitance of the coil, and may be expressed very closely by:

$$Q = Q_e \left(1 + \frac{C_d}{C}\right) \qquad (16)$$

except for frequencies very near the natural frequency of the coil. Thus, the effective Q approaches true Q as the ratio of tuning capacitance to distributed capacitance increases.

From the practical viewpoint this difference is of little importance since in the design of tuned circuits the minimum capacitance used to tune a coil is usually 10 to 20 times the distributed capacitance of the coil so that the maximum difference between effective and true Q will be 5 to 10 per cent when measured with the minimum tuning capacitance.

In special cases when coils having a high distributed capacitance are measured with low tuning capacitances and it is desired to know Q with high accuracy, the above equation (16) may be used to obtain true Q.

UNITS USED IN FORMULAS

In all formulas on the following pages, unless otherwise stated, the units employed are:

L = Inductance in microhenries.
C = Capacitance in micro-microfarads.
f = Frequency in kilocycles per second.
R = Resistance in ohms.
X = Reactance in ohms.
Z = Impedance in ohms.

The subscripts used refer to the following values, unless otherwise stated:

C_d = Distributed capacitance of a coil.
f_o = Resonant frequency of an impedance.
L_1 = Inductance of the coil used in the Q circuit.
C_1, Q_1 = Capacitance and Q of the Q circuit alone (with coil only connected to the Q circuit).
C_2, Q_2 = Capacitance and Q of the Q circuit with the test component connected to the Q circuit.
Q_x = Q of the test component.
C_s, L_s, R_s, X_s = Effective series values of the test component.
C_p, L_p, R_p, X_p = Effective parallel values of the test component.

GENERAL METHODS OF MEASUREMENT

1-A. COIL MEASUREMENTS.

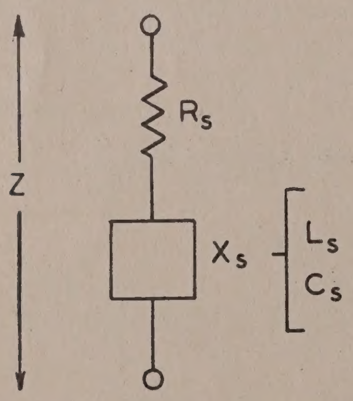
The Q circuit of the Q-Meter consists essentially of a calibrated variable condenser to which an external coil may be connected to form a simple resonant circuit. The inductance of the external coil is substantially the entire inductance of the Q circuit. A calibrated voltage is inserted in series in this circuit and a voltmeter connected across the condenser measures the Q of the circuit.

There are two general methods of making measurements with the Q-Meter. One method which is applicable to measuring coils consists of connecting the unknown coil to the Q circuit, thus making the coil the inductive element of a simple resonant circuit which at resonance indicates, directly, values of tuning capacitance and circuit Q. From these values and the frequency of measurement, the effective Q, inductance, resistance, etc., of the coil may be determined. Because of its simplicity this method is used for most coil measurements. The theory of this method has been discussed on page 2 and the procedure for measuring coils is described in more detail in section 3, page 9.

1-B. MEASUREMENT OF ANY IMPEDANCE.

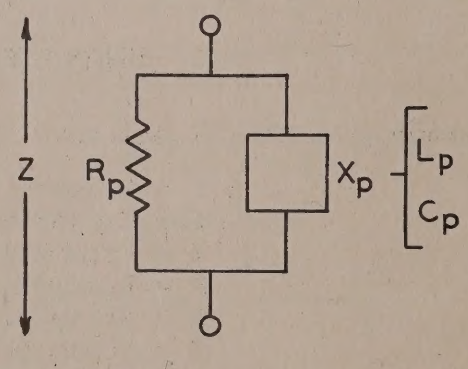
A second method of measurement which is applicable to any two-terminal impedance (within the limits of measurements of the Q-Meter) consists of first, providing a simple resonant circuit by connecting a coil to the Q circuit of the Q-Meter and resonating the circuit, and second, connecting the unknown impedance to the resonant circuit, either in series or in parallel, and re-resonating the circuit. Two values of circuit tuning capacitance and two Q readings are thus obtained. From these values and the frequency of measurement obtained from the Q-Meter, may be calculated effective values of Q, resistance, reactance, inductance or capacitance of the unknown impedance.

Any two-terminal impedance, Z, may be considered as consisting of two elements, one an effective resistance and the other an effective reactance which may be inductive or capacitive. These elements may be thought of as connected either in series as represented in Fig. 2A or in parallel as represented in Fig. 2B.



R_s = Effective series resistance.
X_s = Effective series reactance.
L_s = Effective series inductance.
C_s = Effective series capacitance.

Fig. 2A



R_p = Effective parallel resistance.
X_p = Effective parallel reactance.
L_p = Effective parallel inductance.
C_p = Effective parallel capacitance.

Fig. 2B

The values of the resistance, reactance, inductance and capacitance for the series arrangement may be expressed as effective series values and represented by R_s, X_s, L_s and C_s. The corresponding values for the parallel arrangement may be expressed as effective parallel values and represented by R_p, X_p, L_p and C_p.

The Q of the impedance has the same value whether the impedance is considered as a series or parallel arrangement. The effective series values of the resistance and reactance elements, however, may be quite different from their effective parallel values. The general relations between these quantities are shown in the following formulas (17) to (21):

$$Q_x = \frac{X_s}{R_s} = \frac{6.28 \times 10^{-3}\, f\, L_s}{R_s} = \frac{1.59 \times 10^8}{f\, R_s\, C_s} = \frac{R_p}{X_p} = \frac{159\, R_p}{f\, L_p} = 6.28 \times 10^{-9}\, f\, R_p\, C_p \qquad (17)$$

$$R_s = \frac{R_p}{1 + Q_x^2} \qquad (18a)$$

$$X_s = X_p\, \frac{Q_x^2}{1 + Q_x^2} \qquad (19a)$$

$$L_s = L_p\, \frac{Q_x^2}{1 + Q_x^2} \qquad (20a)$$

$$C_s = C_p\, \frac{1 + Q_x^2}{Q_x^2} \qquad (21a)$$

$$R_p = R_s\, (1 + Q_x^2) \qquad (18b)$$

$$X_p = X_s\, \frac{1 + Q_x^2}{Q_x^2} \qquad (19b)$$

$$L_p = L_s\, \frac{1 + Q_x^2}{Q_x^2} \qquad (20b)$$

$$C_p = C_s\, \frac{Q_x^2}{1 + Q_x^2} \qquad (21b)$$

It is apparent from the above relations that when the Q of an impedance is greater than 10, X_s, L_s and C_s are equal to X_p, L_p and C_p, respectively, with an error of less than one per cent, but the values of R_s and R_p are quite different. This corresponds to the case of coils and condensers commonly used in resonant circuits which generally have Q's considerably greater than 10 and in this case the difference between the effective series and parallel values of reactance, inductance or capacitance is negligible while the difference between the effective series and parallel resistance is large.

It is also apparent that when the Q of the impedance is less than 0.1 as may occur in resistors, R_s and R_p will be equal, with an error of less than one per cent, while the difference between the effective series and parallel values of the reactive element will be large.

The Q and the effective series and parallel values of resistance, reactance, inductance or capacitance of a two-terminal impedance, as defined above, may be measured with the Q-Meter by connecting the unknown impedance, Z, either in series in the Q circuit of the Q-Meter as represented in Fig. 2C or in parallel with the Q circuit as in Fig. 2D. L and C in these figures represent the inductance and resonant capacitance of the Q circuit and E represents the voltage inserted in series with the Q circuit in the Q-Meter. The series connection is generally useful for measuring low impedances and the parallel connection for measuring high impedances.

SERIES CONNECTION

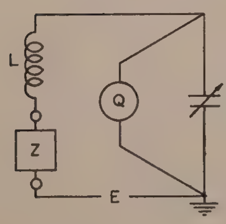


Fig. 2C

PARALLEL CONNECTION

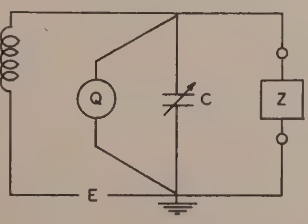


Fig. 2D

When an unknown impedance is measured with the Q-Meter, the effective series values of resistance, reactance, etc., of the impedance are most simply determined from the series connection to the Q circuit (Fig. 2C) whereas the effective parallel values are most simply determined from the parallel connection (Fig. 2D). For this reason the formulas for calculating the effective resistance, reactance, etc., given below have been arranged to give effective series values when the unknown impedance is measured in series in the Q circuit and to give effective parallel values when the impedance is measured in parallel with the Q circuit.

The procedure in measuring an unknown impedance is as follows: The Q circuit is first resonated to the frequency of measurement, f, calling the values of resonant capacitance and the Q of the Q circuit, C_1 and Q_1, respectively. The unknown impedance is then connected to the Q circuit, either in series or parallel, and the Q circuit re-resonated to the same frequency of measurement, f, calling the new resonant capacitance and circuit Q, C_2 and Q_2, respectively. These values may be used directly in the following formulas to calculate effective series or parallel values of resistance, reactance, inductance or capacitance, and the Q of the unknown impedance.

GENERAL FORMULAS FOR ANY IMPEDANCE

SERIES CONNECTION TO Q CIRCUIT (Fig. 2C)

$$Q_x = \frac{(C_1-C_2)\ Q_1\ Q_2}{C_1\ Q_1-C_2\ Q_2} \qquad (22a)$$

$$R_s = \frac{1.59 \times 10^8 \left(\frac{C_1}{C_2} Q_1-Q_2\right)}{f\ C_1 Q_1 Q_2} \qquad (23a)$$

$$X_s = \frac{1.59 \times 10^8\ (C_1-C_2)}{f\ C_1 C_2} \qquad (24a)$$

$$L_s = \frac{2.53 \times 10^{10}\ (C_1-C_2)}{f^2 C_1 C_2} \qquad (25a)$$

$$C_s = \frac{C_1\ C_2}{(C_2-C_1)} \qquad (26a)$$

When C_1 is:
Greater than C_2, X_s is inductive (+).
Less than C_2, X_s is capacitive (–).

PARALLEL CONNECTION TO Q CIRCUIT (Fig. 2D)

$$Q_x = \frac{(C_2-C_1)\ \ Q_1\ Q_2}{C_1(Q_1-Q_2)} \qquad (22b)$$

$$R_p = \frac{1.59 \times 10^8\ \ Q_1\ Q_2}{f\ C_1(Q_1-Q_2)} \qquad (23b)$$

$$X_p = \frac{1.59 \times 10^8}{f\ (C_2-C_1)} \qquad (24b)$$

$$L_p = \frac{2.53 \times 10^{10}}{f^2\ (C_2-C_1)} \qquad (25b)$$

$$C_p = C_1-C_2 \qquad (26b)$$

When C_1 is:
Greater than C_2, X_p is capacitive (–).
Less than C_2, X_p is inductive (+).

In the formulas for Q, the quantities $(C_1–C_2)$ and $(C_2–C_1)$ are always considered positive.

The following symbols used in the above formulas refer to the Q-Meter readings:

C_1, Q_1 = Capacitance and Q readings of Q circuit alone.
C_2, Q_2 = Capacitance and Q readings of Q circuit with unknown impedance, Z, connected either in series or in parallel with the circuit.
f = Frequency of measurement.

The following symbols refer to values of the unknown impedance, Z:

Q_x = Q of the unknown impedance.

R_s = Effective series resistance.
X_s = Effective series reactance.
L_s = Effective series inductance.
C_s = Effective series capacitance.

R_p = Effective parallel resistance.
X_p = Effective parallel reactance.
L_p = Effective parallel inductance.
C_p = Effective parallel capacitance.

The units used are:

R = Resistance in ohms.
X = Reactance in ohms.
L = Inductance in microhenries.
C = Capacitance in micro-microfarads.
f = Frequency in kilocycles per second.

It is apparent that when an impedance is connected, for example, in parallel with the Q circuit, the values obtained from the preceding formulas (23b) to (26b) are effective parallel values. If equivalent series values are desired, for example effective series resistance, it may be obtained by first calculating Q_x by means of formula (22b) and the effective parallel resistance, R_p, from formula (23b), then substituting Q_x and R_p in formula (18a), page 5, to obtain the effective series resistance R_s.

In a similar manner effective parallel values may be calculated from measured series values by calculating first the series values of R_s, X_s, L_s or C_s and the Q of the impedance, Q_x, from formulas (22a) to (26a) and making the necessary substitutions in formulas (18b) to (21b) to obtain parallel values.

1-C. SIMPLIFIED FORMULAS FOR HIGH Q IMPEDANCES.

In some cases the calculation of desired quantities may be simplified. When the Q of the impedance being measured is greater than 10 as will be the case in many components, the difference between the effective series and parallel values of reactance, inductance or capacitance may be neglected and the values obtained from the preceding formulas (24) to (26) may be considered to be the effective reactance, inductance or capacitance of the impedance without regard to whether they are series or parallel values. The values of R_s and R_p in this case will be quite different as shown in the following group of formulas:

FORMULAS FOR IMPEDANCES HAVING A Q GREATER THAN 10

SERIES CONNECTION TO Q-METER
(Fig. 2C)

$$Q_x = \frac{(C_1 - C_2)\, Q_1 Q_2}{C_1 Q_1 - C_2 Q_2} \qquad (22a)$$

$$R_s = \frac{1.59 \times 10^8 \left(\frac{C_1}{C^2} Q_1 - Q_2 \right)}{f\ C_1\, Q_1 Q_2} \qquad (23a)$$

$$R_p = \frac{1.59 \times 10^8 (C_1 - C_2)^2\, Q_1 Q_2}{f\ C_1 C_2\, (C_1 Q_1 - C_2 Q_2)} \qquad (27a)$$

$$X_s = X_p = \frac{1.59 \times 10^8 (C_1 - C_2)}{f\ C_1 C_2} \qquad (28a)$$

$$L_s = L_p = \frac{2.53 \times 10^{10} (C_1 - C_2)}{f^2\ C_1 C_2} \qquad (29a)$$

$$C_s = C_p = \frac{C_1 C_2}{(C_2 - C_1)} \qquad (30a)$$

PARALLEL CONNECTION TO Q-METER
(Fig. 2D)

$$Q_x = \frac{(C_2 - C_1)\, Q_1 Q_2}{C_1\ (Q_1 - Q_2)} \qquad (22b)$$

$$R_p = \frac{1.59 \times 10^8\, Q_1 Q_2}{f\, C_1\, (Q_1 - Q_2)} \qquad (23b)$$

$$R_s = \frac{1.59 \times 10^8\, C_1\, (Q_1 - Q_2)}{f\, (C_2 - C_1)^2\, Q_1 Q_2} \qquad (27b)$$

$$X_s = X_p = \frac{1.59 \times 10^8}{f\, (C_2 - C_1)} \qquad (28b)$$

$$L_s = L_p = \frac{2.53 \times 10^{10}}{f^2\, (C_2 - C_1)} \qquad (29b)$$

$$C_s = C_p = C_1 - C_2 \qquad (30b)$$

In the above formulas the same units, symbols and conditions stated on page 6 apply except that formulas (27) to (30) are accurate only for impedances having a Q greater than 10. Formulas (22) and (23) are accurate for any impedance.

GENERAL PRECAUTIONS

2-A. Q CIRCUIT COILS.

Measurements of components other than coils, such as condensers, resistors, etc., require a coil in the Q circuit of the Q-Meter for resonating to the frequency of measurement. The main requirements for this coil are (1) that its inductance is of such a value that it will resonate to the desired frequency of measurement with the total tuning capacitance desired (the sum of the capacitance used in the Q tuning condensers and the capacitance of the component being measured), and (2) that its Q is high enough to permit accurate measurements. Generally a Q in the region of 200 to 250 will be most suitable. For some measurements, such as Q or power factor of low loss condensers or insulating materials, a coil having a higher Q (400 to 500) is desirable.

The coil should preferably be shielded to avoid coupling to the test component and to prevent any nearby objects from changing the Q circuit adjustment during measurement. Large unshielded coils are particularly subject to such changes because of the extent of their field and should not be used ordinarily for accurate measurement work. The coil shield should be grounded to the low potential coil terminal.

If measurements are to be made over a wide range of frequencies, a number of such coils are required each of which may be used for a single or a narrow band of frequencies.

The Type 103-A Inductors are suitable for this purpose, having been designed to plug into the coil terminals of the Q-Meter to facilitate rapid changing of inductance to correspond to the measurement frequency. They are completely shielded coils having a Q in the region of 200 over the normal range of operation (when resonated with tuning capacitances between 40 and 400 $\mu\mu$f).

2-B. PRECAUTIONS.

In all measurements, unless otherwise stated, the Q circuit is to be adjusted to resonance as indicated by a maximum deflection of the Q voltmeter. The dial readings and Q readings at resonance are the values to be used in the formulas in calculating quantities not directly indicated. Unless otherwise stated the vernier condenser should be set at zero or its capacitance should be added to the main condenser dial reading.

All ordinary precautions observed in making radio frequency measurements, such as placing the component being measured so that any field surrounding it is not appreciably affected by nearby conductors or by capacitance to the body of the operator, maintaining low resistance connections, etc., should be observed.

Leads between the Q-Meter and the component being measured should be heavy and as short as possible when making measurements at high frequencies.

Owing to the method of insertion of the voltage in the Q circuit the low potential coil terminal is not at ground potential. Care should be taken that components connected to the coil terminals are not grounded either to the Q-Meter cabinet or to ground since this will prevent correct operation of the Q circuit. Components or circuits having a ground connection or large capacitance to ground can not be measured when connected to the coil terminals of the Q-Meter. Such components may in some cases be connected in parallel with the Q circuit (to the condenser terminals) for measurement.

When measuring components other than coils, the determination of Q, resistance or power factor generally depends on the component in question having losses great enough to produce a measurable change in the Q of the Q circuit. That is, the Q of the component must be comparable to the Q of the Q circuit. It is apparent that a condenser having a very high Q, for example, may lower the Q of the Q circuit by only a very small amount when it is connected across the circuit and if this change in Q is too small to measure, the Q or resistance of the test condenser can not be measured.

In measurements such as Q or resistance of condensers in which the accuracy depends on the accuracy of the total tuning capacitance, the capacitance between any leads should be taken into account by disconnecting the condenser *at its terminals* and measuring the effect of the leads by noting the change in the resonant capacitance of the main tuning condenser when the leads are connected and disconnected. This also applies to any fixtures used in testing. Their capacitances should be determined and added to the readings of the main tuning condenser. This is particularly important in determining the distributed capacitance of a coil, which may be quite low. In general, testing fixtures should be made of low-loss insulating materials.

Q voltmeter readings of less than about 100 are limited in accuracy by the meter calibration. Meters are generally rated in accuracy as a percentage of full scale so it is apparent that the accuracy of a reading expressed as a percentage of the reading decreases as the reading decreases.

COILS

3-A. GENERAL.

When a coil is measured with the Q-Meter its inductance is the entire inductance of the Q circuit except for the residual inductance of the circuit. The tuning capacitance at resonance is indicated directly by the tuning condenser dial, and the Q of the circuit is indicated directly by the Q voltmeter. This Q indication is the Q of the entire resonant circuit, but this is equal to the Q of the coil when the inductance and losses of the rest of the circuit are negligible compared to those in the coil.

When the coil being measured is unshielded, it should be mounted at sufficient distance from the metallic top of the Q-Meter so that the effect of this on the resistance or inductance of the coil is negligible. However, the leads should not be longer than necessary to secure this result.

When measuring shielded coils the shield should be grounded to the low potential coil terminal. In no case should the shield be grounded to *both* the low potential coil terminal and condenser terminal since the series voltage in the Q circuit is inserted between these two terminals.

In measurements requiring two coils in the Q circuit care should be taken to avoid coupling between the coils. One of the coils, at least, should be shielded.

3-B. MEASUREMENT OF Q.

The Q of a coil may be measured as follows: Connect the coil to the coil terminals of the Q-Meter, set the oscillator to the desired frequency and the oscillator output to the 250 or 500 line on the Q range meter, and resonate the Q circuit by means of the Q tuning condenser. The Q voltmeter reading at resonance indicates directly the Q of the coil.

The Q tuning condenser dial indicates the total tuning capacitance of the Q circuit, except that added by the coil and its leads.

Q, as measured above, is the effective Q of the coil and differs from true Q which is defined as $\omega L/R$, by an amount which depends on the distributed capacitance of the coil (see page 3). For most coils measured with the Q-Meter this difference is negligible since the minimum tuning capacitance is generally 10 to 20 times the distributed capacitance and the maximum difference between true Q and effective Q will generally be 5 to 10 per cent.

When coils having a high distributed capacitance are resonated with low tuning capacitances and it is desired to know true Q with greater accuracy than the above measurement provides, true Q may be obtained as follows: Measure effective Q as described above and call this Q_e. Call the Q tuning condenser dial reading C_1. Measure the distributed capacitance, C_d, of the coil by one of the methods described below in sections 3-F or 3-G. True Q is then:

$$Q = Q_e \left(\frac{C_1 + C_d}{C_1}\right) \qquad (31)$$

3-C. RESISTANCE.

The effective series resistance of a coil may be determined by first measuring its effective Q as described above, recording the values of frequency, f, Q condenser tuning capacitance, C_1, and the Q of the coil, Q_1. The resistance, R_s, of the coil is then:

$$R_s = \frac{1.59 \times 10^8}{f\, C_1\, Q_1} \qquad (32)$$

The resistance, R_s, obtained is the apparent resistance, or effective series resistance of the coil. For most coils this value will be practically the same as the true resistance when measured as described.

The true resistance, R, of a coil differs from the apparent resistance because of the distributed capacitance of the coil, and for frequencies not too close to the resonant frequency of the coil the relation between true resistance, R, and apparent resistance, R_s, is given by:

$$R = R_s \left(\frac{C_1}{C_1 + C_d}\right)^2 \qquad (33)$$

in which C_1 is the tuning capacitance used when measuring the resistance (or Q) and C_d is the distributed capacitance of the coil.

When a coil is measured with relatively low tuning capacitances and its distributed capacitance is sufficiently high so that there is an appreciable difference between true resistance and apparent resistance, the true resistance may be determined as follows: Measure the apparent resistance, R_s, as described above. Measure the distributed capacitance of the coil, C_d, by one of the methods described below in sections 3-F and 3-G, and calculate the true resistance, R, using the above formula (33).

3-D. INDUCTANCE.

The inductance of coils having inductances from a few tenths of a microhenry to a few tenths of a henry may be measured with an accuracy of about 3 per cent with the type 160-A Q-Meter when used

in conjunction with an external oscillator for operation between 50 Kc and the region of 1 Kc (see page 21). The range of inductance measurements with the type 100-A is less and with the type 170-A much less. The L, C, F chart on page 34 will be found helpful in determining the range of inductance values that may be resonated with each instrument.

The inductance of a coil may be measured as follows: Connect the coil to the coil terminals of the Q-Meter, set the Q tuning condenser to about 400 $\mu\mu$f, and resonate the Q circuit by adjusting the oscillator frequency. Record the frequency, f, and the tuning condenser reading, C_1. The inductance, L_s, is:

$$L_s = \frac{2.53 \times 10^{10}}{f^2 C_1} \quad (34)$$

If the Q tuning condenser is set to exactly 400 $\mu\mu$f, this formula may be simplified to:

$$L_s = \frac{63.2 \times 10^6}{f^2} \quad (35)$$

This measurement gives the apparent or effective series inductance, L_s, of the coil. For most coils measured as described above this will differ from the true inductance, L, by an amount which is less than the accuracy of measurement.

True inductance is less than apparent inductance by an amount which depends on the distributed capacitance of the coil. Good small coils generally have a distributed capacitance in the region of 1 to 6 $\mu\mu$f, and for these coils the maximum difference between true inductance and apparent inductance will be about 1.5 per cent when measured as described above.

The true inductance of coils having a high distributed capacitance or high capacitance between leads may be determined by measuring the apparent inductance, L_s, as described above, and measuring the distributed capacitance, C_d, of the coil by one of the methods described below in sections 3-F or 3-G. True inductance, L, is then:

$$L = L_s \left(\frac{C_1}{C_1 + C_d}\right) \quad (36)$$

C_1 is the tuning capacitance used when measuring the apparent inductance. This formula applies for frequencies not too near the resonant frequency of the coil.

3-E. SMALL INDUCTANCE IN SERIES WITH LARGE INDUCTANCE.

A small inductance may be measured by connecting it in series with a coil having an inductance about the same or larger than the inductance to be measured. The accuracy of this measurement becomes less as the ratio of large to small inductance increases. Small inductances less than 0.01 microhenry have been measured at high frequencies in this way although the accuracy of measurement of such small values is not very great.

To determine the inductance of a small inductor: Connect a suitable coil (see section 2-A, page 8) to the coil terminals of the Q-Meter, set the oscillator frequency to a value that will permit resonating the Q circuit with the Q tuning condenser set at about 400 $\mu\mu$f and resonate the Q circuit. Call the tuning capacitance C_1 and the frequency f. Connect the small inductor in series with the coil, taking care that no coupling exists between the coil and the small inductor, and re-resonate the Q circuit, calling the new tuning capacitance C_2. The effective series inductance, L_s, of the small inductor is:

$$L_s = \frac{2.53 \times 10^{10} (C_1 - C_2)}{f^2 C_1 C_2} \quad (25a)$$

Other values such as Q, resistance, etc., of the small inductor may be calculated from the formulas (22a) to (24a), page 6, which give the effective series values of an impedance measured in series in the Q circuit.

3-F. DISTRIBUTED CAPACITANCE.

A simple method of measuring the distributed capacitance of a coil which is fairly accurate for high distributed capacitances but is inaccurate for capacitances below about 10 $\mu\mu$f is as follows: Connect the coil to the coil terminals of the Q-Meter. Set the Q circuit capacitance to about 50 $\mu\mu$f, calling this capacitance C_1, and resonate the Q circuit by adjusting the oscillator frequency to exact resonance. Set the oscillator to a new frequency exactly one-half of the first resonant frequency. Retune the Q circuit by means of the Q tuning condenser and call the new condenser reading C_2. The distributed capacitance, C_d, is then:

$$C_d = \frac{C_2 - 4C_1}{3} \quad (37)$$

This procedure may be repeated with different values of C_1 and the values of C_d averaged to obtain somewhat greater accuracy. The best accuracy to be expected with this method is of the order of plus or minus 2 $\mu\mu$f.

3-G. RESONANT FREQUENCY AND DISTRIBUTED CAPACITANCE.

A more accurate method of determining the distributed capacitance of a coil when the capacitance is less than about 20 to 30 $\mu\mu$f, involves measuring the resonant frequency of the coil.

The resonant frequency of a coil may be determined with the Q-Meter by an indirect method which has the advantage of being quite accurate and is applicable to almost any type of coil, shielded or unshielded, within the range of the Q-Meter. This method depends on the fact that at the resonant frequency of a coil, the impedance across its terminals is effectively a non-reactive resistance, and consists of making a number of settings of the Q-Meter frequency and resonating the Q circuit at each frequency with the test coil first disconnected and then connected across the Q circuit, until a frequency is found at which the connection of the test coil causes no change in the Q circuit tuning. The following procedure is recommended to aid in locating the resonant frequency of a coil:

I. Connect the test coil to the *coil* terminals of the Q-Meter, set the Q tuning condenser to about 400 $\mu\mu$f, and resonate the Q circuit by adjusting the oscillator frequency. Call the frequency f_1 and tuning capacitance C_1.

II. Replace the test coil with a shielded coil having an inductance about 1/25 of that of the test coil, or a coil that will resonate in the Q circuit to a frequency about 10 times the value of f_1. Set the Q-Meter to a frequency of about 10 times f_1 and resonate the Q circuit to this new frequency. (This factor of 10 is based on the distributed capacitance of the coil being in the region of 4 $\mu\mu$f, which is common for small coils. Higher distributed capacitances will lower the resonant frequency of the coil and a smaller factor than 10 will obtain.)

III. Connect the test coil across the Q circuit (to the condenser terminals), taking care to avoid coupling between the two coils, and re-resonate the Q circuit by means of the Q tuning condenser or vernier condenser, *observing whether the capacitance has to be increased or decreased* from its previous value to restore resonance.

If the capacitance has to be INCREASED, INCREASE the oscillator frequency by an appreciable amount (10 to 20 per cent). If the capacitance has to be DECREASED, DECREASE the oscillator frequency.

IV. Disconnect the test coil and resonate the Q circuit to the new frequency by means of the Q tuning condenser. Repeat the above procedure III, changing the oscillator frequency by smaller increments as it approaches the resonant frequency of the test coil, until the frequency reaches a value at which the Q circuit capacitance is unchanged when the test coil is connected or disconnected.

The oscillator frequency is then the resonant frequency of the test coil. Call this frequency f_o.

The distributed capacitance, C_d, of the coil may be calculated from the values of f_1 and C_1 obtained in paragraph I above, and the resonant frequency, f_o, of the coil, using the following formula:

$$C_d = \left(\frac{f_1}{f_o}\right)^2 C_1 \qquad (38)$$

The accuracy of this distributed capacitance measurement depends on the inductance of the coil being the same at the two measurement frequencies. This is reasonably accurate for commonly used coils, although it may not hold for coils having iron cores.

SMALL CONDENSERS

4-A. GENERAL.

Measurements of the capacitance and Q (or power factor) of small condensers can be made with the Q-Meter if the capacitance of the test condenser is within the $\triangle$ C range of the Q tuning condenser of the Q-Meter. The accuracy with which such measurements can be made is dependent on the capacitance, inductance and Q of the test condenser, the frequency of measurement and the technique employed. In general, the accuracy of capacitance measurements is within ±2% and the accuracy of Q measurements is within ±10%. Under certain conditions greater accuracies can be obtained. In the higher frequency region (above 30-40 Mc with the type 160-A and above 5-10 Mc with the type 100-A Q-Meter) the accuracy of the Q and C measurement will decrease.

Above a few megacycles the inductance and resistance of leads connecting the condenser posts of the Q-Meter and the test condenser proper become increasingly important and accordingly should be made of short, wide, conducting strip.

If the capacitance of the condenser is small, i.e., a few $\mu\mu$f, the capacitance of the leads may become comparable to that of the test condenser, and may require correction.

The internal inductance of condensers (and their leads) becomes more and more important with increasing frequency. This is indicated by an increase in the apparent capacitance of the condenser. Referring to the chart on page 34, it will be noted that a 1,000 $\mu\mu$f condenser will resonate at 50 Mc with an inductance of .01 μhy, a 100 $\mu\mu$f condenser will resonate at 160 Mc with .01 μhy, etc. The increase in apparent capacitance of the condenser will be evident at frequencies considerably below the resonant frequency.

The accuracy of measuring the Q of a component such as a condenser when it is connected in parallel with the Q circuit is also related to its effect on the Q of the Q circuit. A consideration of the equations from which the Q or resistance of the component is calculated indicates that the accuracy of this measurement will increase as the $\triangle$ Q (i.e., Q_1–Q_2) increases. However, since the accuracy of the Q voltmeter calibration is a function of full scale reading, it is obvious that very low Q_2 readings may be inaccurately indicated and that an optimum operating region will exist which is determined by the values involved. From a practical viewpoint, it will be found that most condensers can be measured with greater accuracy when they are closely coupled to the measuring circuit, i.e., when their capacitance is a large percentage of the total circuit capacitance. Condensers with very poor dielectric are the exception and the measuring technique must be modified to fit the conditions. With such condensers, the C_2 setting of the Q condenser should be increased until the Q_2 value can be accurately read.

MEASURING TECHNIQUE:

Experience has shown that, in general, the most accurate method of determining the capacitance, the Q, the series and the parallel resistance of a condenser is as follows:

1. Connect the test condenser to the Q-Meter, observing the precautions previously mentioned.
2. Set the Q tuning condenser to some convenient low capacitance value, e.g., 30 $\mu\mu$f. Record this as C_2.
3. Select a coil which will resonate with the capacitance of the test condenser plus the capacitance setting of the Q tuning condenser to the desired frequency of measurement.
4. Adjust the oscillator frequency to resonate the Q circuit. Fine adjustment may be made with the vernier Q condenser, changing this by perhaps a few tenths of a micromicrofarad.
5. Record the circuit Q reading as Q_2.
6. Remove the test condenser.
7. Retune the Q circuit, noting the circuit Q at resonance. Record the Q condenser setting as C_1 and the circuit Q reading as Q_1. An average curve drawn through a number of measurements, especially if fairly closely spaced over a frequency range will further increase the accuracy of this measurement.

4-B. CAPACITANCE.

The capacitance of the test condenser is:

$$C_p = C_1 - C_2 \qquad (26b)$$

The value of C_p thus obtained is the effective parallel capacitance of the test condenser. The difference between this value and effective series capacitance is negligible for condensers having a Q greater than about 10, which will be the case for most small

condensers used in radio circuits. When the Q of a condenser or an impedance is 10 or less, the effective series capacitance may be determined as described in section 1-B, page 4.

It is important, especially when measuring very small capacitances, that the measurement excludes the capacitance of leads to the test condenser. This may readily be accomplished by connecting suitable leads to the Q-Meter before making the initial resonance setting of the Q circuit and connecting the test condenser at the end of the leads, taking care not to change the position of the leads during the measurement.

One very useful feature of the above method is that it provides a relative indication of losses in the test condenser simultaneously with the capacitance measurement, as indicated by the drop in Q of the Q circuit when the test condenser is connected.

For capacitance measurements of greater accuracy than this method provides, the following method should be used.

4-C. ACCURATE CAPACITANCE MEASUREMENTS USING EXTERNAL CONDENSER.

By the use of a calibrated standard condenser (such as a precision condenser) in conjunction with the Q-Meter, the capacitance of small condensers may be measured with a high degree of accuracy which is limited generally only by the accuracy of calibration of the standard condenser since the accuracy of setting the condenser is generally greater than the accuracy of calibration.

To measure capacitances using an external condenser, this condenser should be connected to the condenser terminals of the Q-Meter, and the same general procedure described above in section 4-B should be followed except that all capacitance settings and observations should be made with the external condenser instead of the Q tuning condenser. The following additional precautions should be observed:

The length of leads required to connect a large condenser to the Q-Meter, together with the internal inductance of such a condenser, limit the maximum frequency of accurate measurement to the region of 500 kilocycles. It is advisable to set the frequency of measurement in the neighborhood of 200 kilocycles to permit using leads up to about a foot in length. This frequency requires a coil for use in the Q circuit having an inductance in the region of 1 or 2 millihenries (see section 2-A).

All leads used should be fairly rigid and well supported to avoid accidental changes in circuit capacitance, especially when measuring small capacitances. Connections to the test condenser should be made at the condenser terminals to exclude lead capacitances from the measurement. The test condenser should be connected directly to the standard condenser.

4-D. POWER FACTOR AND Q.

The power factor, Q, and resistance of small condensers having Q's of less than about 2000 to 6000 (power factors greater than about 0.015 to 0.05 per cent) can be measured with the Q-Meter.

The maximum Q that can be measured depends on the capacitance of the test condenser and the Q of the Q circuit. The measurement of Q requires measuring the drop in Q of the Q circuit when the condenser is connected across the circuit. This decrease in Q becomes smaller as the Q of the test condenser becomes large compared to the Q of the Q circuit, and also as the capacitance of the test condenser becomes smaller. It is apparent, therefore, that when the Q of the test condenser is high enough it will not produce a measurable difference in the Q of the Q circuit and therefore its Q or resistance can not be measured.

In general, the Q of commonly used mica or other solid dielectric condensers, air dielectric condensers with poor insulation, etc., may be measured. However, good air dielectric condensers usually have a Q too high to be measured.

The general precautions described in sections 4-A and 4-B should be observed in measuring power factor or Q. The Q of the test condenser, Q_x, is

$$Q_x = \frac{(C_1-C_2)\ Q_1\ Q_2}{C_1(Q_1-Q_2)} \tag{39}$$

The power factor of the test condenser in per cent (for values less than about 10%) is:

$$\text{Power Factor} = \frac{100}{Q_x} = \frac{100\ C_1\ (Q_1-Q_2)}{(C_1-C_2)\ Q_1\ Q_2} \tag{40}$$

4-E. RESISTANCE.

The resistance of a small condenser having a Q of less than about 2000 to 6000 may be determined by following the procedure described in the preceding section 4-D, obtaining the values of Q circuit tuning capacitance and Q, C_1 and Q_1, without the test condenser connected, and C_2 and Q_2 with the test condenser connected, and the frequency of measurement, f.

The effective parallel resistance, R_p, of the test condenser is:

$$R_p = \frac{1.59 \times 10^8 Q_1 Q_2}{f C_1 (Q_1 - Q_2)} \qquad (23b)$$

This formula is accurate for condensers or impedances having any Q.

The effective series resistance, R_s, for condensers having a Q of more than about 10 is:

$$R_s = \frac{1.59 \times 10^8 \ C_1 \ (Q_1 - Q_2)}{f \ (C_1 - C_2)^2 \ Q_1 \ Q_2} \qquad (27b)$$

The effective series or parallel resistance of condensers or impedances having a Q of 10 or less may be determined by the method described in section 1, page 4.

If the effective series capacitance, C_s, and the Q, Q_x, of the test condenser are known the effective series resistance, R_s, is:

$$R_s = \frac{1.59 \times 10^8}{f \ C_s \ Q_x} \qquad (41)$$

INSULATING MATERIALS

5-A. GENERAL.

The fundamental properties of interest in connection with insulating materials are the dielectric constant ϵ and the losses as expressed by Q or power factor. These quantities may be determined for most insulating materials by making a condenser out of a sample of the material and measuring this condenser as described in the preceding section 4.

Thin sheets of insulating material are most convenient for this purpose and may be provided with tin foil conducting surfaces by applying a thin film of vaseline (or similar material having low losses) to the sample of insulating material and pressing and rubbing the tin foil into close contact with the sample, excluding all air pockets. Connections to the tin foil surfaces may be made by means of two copper or brass strips or heavy wire attached to the Q-Meter condenser terminals, and shaped so that they make contact with the tin foil when the prepared sample is placed between these connecting leads. The contact surfaces should be kept clean.

Mercury electrodes may be used by means of the conventional method of floating the sample on the surface of mercury contained in a suitable dish, placing a metal ring (or rectangle) on top of the sample and filling inside the ring with mercury. Suitable leads should be provided for connecting the mercury electrodes to the Q-Meter.

Oils or other fluids require a cell or container with suitable electrodes between which the fluid to be measured may be placed.

In any case, in order to reduce edge effects, the area of the active dielectric between the electrodes should be large compared to the thickness of the dielectric. The sample condenser should be dimensioned so that its capacitance does not exceed the Δ C available in the Q tuning condenser.

5-B. DIELECTRIC CONSTANT.

To determine the dielectric constant, ϵ, of a sample of insulating material: Prepare it as described above, and measure its capacitance according to the method given in section 4-B, page 12, and call this value C. Measure the area of the active dielectric contained between the electrodes, calling this value S, and measure the average thickness of the active dielectric, calling this value t. When C is in micro-microfarads and S and t are in inches, the dielectric constant is:

$$\epsilon = \frac{4.45 \ C t}{S} \qquad (42)$$

When S and t are measured in centimeters, the dielectric constant is:

$$\epsilon = \frac{11.3 \ C t}{S} \qquad (43)$$

5-C. POWER FACTOR AND Q.

To determine the power factor or Q of a sample of insulating material, the sample should be prepared as described above, and then measured as a small condenser as described in section 4-D, page 13. For convenience the formulas are repeated here:

If C_1 and Q_1 are the capacitance and Q of the Q circuit at resonance with the sample not connected, and C_2 and Q_2 are the capacitance and Q of the circuit with the sample connected, then the Q of the insulating material is:

$$Q_x = \frac{(C_1 - C_2) \ Q_1 \ Q_2}{C_1 (Q_1 - Q_2)} \qquad (39)$$

The power factor in per cent (for values less than about 10%) is:

$$\text{Power Factor} = \frac{100}{Q_x} = \frac{100 \ C_1 \ (Q_1 - Q_2)}{(C_1 - C_2) \ Q_1 \ Q_2} \qquad (40)$$

LARGE CONDENSERS

6-A. GENERAL.

A large condenser may be measured by connecting it in series with a coil and connecting this combination to the coil terminals of the Q-Meter with the test condenser connected to the low potential side of the coil.

For this measurement a coil is required having an inductance which will resonate to the desired test frequency with the Q tuning condenser set to a high capacitance value, so that connecting and disconnecting the test condenser will produce a measurable change in the C and Q of the measuring circuit.

A resistor having a resistance of not over 10 megohms is also required which must be connected across the test condenser when it is in the Q circuit to provide a d.c. path for the grid bias of the vacuum tube voltmeter.

It is important when measuring large condensers to observe the precaution of including as little inductance as possible in the condenser leads during the measurements, as the internal inductance of the condenser will usually be small and even an inch or two of lead may cause a serious error. When measuring the circuit without the condenser, it is generally desirable to leave the condenser in the circuit and short it out at the condenser terminals with a heavy copper jumper without changing the position of any leads. This will reduce errors caused by lead inductance to a minimum.

6-B. CAPACITANCE AND INDUCTANCE.

The effective capacitance of condensers up to about 0.1 or 0.2 μf may be measured by resonating the Q circuit by means of the Q tuning condenser, first without the test condenser (or with the test condenser shorted out), then with the test condenser in series with the low potential side of the coil. Small changes in tuning capacitance may be read on the vernier condenser dial. The two readings of tuning capacitance of the Q circuit should be recorded.

Let C_1 represent the tuning capacitance setting without the test condenser, and C_2 the tuning capacitance with the test condenser connected in series with the coil. Then the effective series capacitance, C_s, of the test condenser is:

$$C_s = \frac{C_1 C_2}{(C_2 - C_1)} \qquad (26a)$$

If C_1 is larger than C_2 the effective reactance of the test condenser is inductive and its effective series inductance, L_s, is

$$L_s = \frac{2.53 \times 10^{10} (C_1 - C_2)}{f^2 C_1 C_2} \qquad (25a)$$

or if the effective inductance, L_1, of the coil used in the Q circuit is known, the effective series inductance, L_s, of the test condenser is:

$$L_s = L_1 \frac{(C_1 - C_2)}{C_2} \qquad (44)$$

At the resonant frequency of the condenser $C_1 = C_2$ and the condenser is effectively a non-reactive resistance. The effective resistance may be determined as described below.

6-C. RESISTANCE, POWER FACTOR AND Q.

The effective resistance, power factor and Q of a limited range of large condensers may be measured with the Q-Meter by connecting the condensers in series in the Q circuit when such condensers have losses great enough to lower the Q of the Q circuit appreciably. For example, the Q of a test condenser having a capacitance of about 400 $\mu\mu$f may be measured when the Q of the test condenser is less than about 2000. If the test condenser capacitance is about 4000 $\mu\mu$f, its Q may be measured when it is not over about 300, and for larger condensers the maximum Q that can be measured is correspondingly lower.

The Q of the test condenser, Q_x, is:

$$Q_x = \frac{(C_2 - C_1)\ Q_1 Q_2}{C_1 Q_1 - C_2 Q_2} \qquad (22a)$$

The power factor of the test condenser in per cent for values less than about 10 per cent is the reciprocal of Q, times 100, or:

$$\text{Power Factor} = \frac{100}{Q_x} = \frac{100\ (C_1 Q_1 - C_2 Q_2)}{(C_2 - C_1)\ Q_1 Q_2} \qquad (45)$$

The effective series resistance, R_s, of the test condenser is:

$$R_s = \frac{1.59 \times 10^8 \left(\frac{C_1}{C_2} Q_1 - Q_2\right)}{f\ C_1\ Q_1 Q_2} \qquad (23a)$$

6-D. IMPEDANCE.

To determine the impedance of a large condenser, first measure its effective series resistance, R_s, as described in the preceding section 6-C. Then calculate the effective series reactance, X_s, of the test condenser from the values of C_1, C_2, and f obtained in the resistance measurement, as follows:

$$X_s = \frac{1.59 \times 10^8 (C_2 - C_1)}{f\, C_1\, C_2} \tag{24a}$$

or if the reactance of the condenser is inductive use $C_1 - C_2$ in place of $C_2 - C_1$. If the effective series capacitance, C_s, or inductance, L_s, of the test condenser has already been determined, its reactance may be calculated by means of one of the following formulas:

$$X_s = \frac{1.59 \times 10^8}{f\, C_s} \tag{46}$$

$$X_s = 6.28 \times 10^{-3}\, f\, L_s \tag{47}$$

The impedance, Z_x, of the test condenser may then be calculated from the values of resistance, R_s, and reactance, X_s, just determined as follows:

$$Z_x = \sqrt{R_s^2 + X_s^2} \tag{48}$$

6-E. BYPASS CONDENSERS.

Bypass condensers having capacitances not too high may be measured according to the preceding sections 6-A to 6-D. In many cases, however, it may be unnecessary to measure the constants of a condenser. When a bypass condenser is used in series in a tuned circuit, the effect of its resistance on the Q of the circuit and its reactance on the tuning of the circuit may be observed directly by connecting an equivalent circuit to the Q-Meter with the bypass condenser in series with the coil, and observing the change in circuit Q and tuning capacitance when the bypass condenser is shorted out. The bypass condenser should be shunted by a resistance of not over 10 megohms for this test.

The difference in Q tuning condenser settings indicates the relative reactance of the test condenser and whether its reactance is capacitive or inductive. (See section 6B). The change in circuit Q shows directly the lossing effect of the bypass condenser on the circuit.

The same general precautions for measuring large condensers described in the preceding sections 6-A and 6-B should be observed.

RESISTORS

7-A. GENERAL.

The effective resistance of resistors that are comparable to either the series or the anti-resonant resistance of a tuned circuit resonated to the frequency of measurement, may be measured with the Q-Meter at frequencies up to about 30-40 megacycles by connecting the resistors in series or parallel with the Q circuit of the Q-Meter. In general two ranges of resistance can be measured; a range of low values comparable to the series resistance of the tuned circuit and a range of high values comparable to the anti-resonant resistance of the circuit. Both ranges decrease in value with increasing frequency.

For example, at 1000 kc a resonant circuit having a Q of about 200 and C of about 100 $\mu\mu$f, has a series resistance of about 8 ohms, and an anti-resonant resistance of about 300,000 ohms. Using this circuit, resistors connected in series with the tuned circuit having values from about 1 to 30 ohms, and resistors connected in parallel with the circuit having values from about 100,000 ohms to 3 megohms may be measured.

At 10 megacycles a similar circuit would have 1/10 these values of resistance and the corresponding ranges of resistances that may be measured are about 0.1 to 3 ohms and 10,000 to 300,000 ohms.

Within these limitations the effective resistance of resistors may be determined as follows:

7-B. LOW RESISTANCE IN SERIES WITH Q CIRCUIT.

Connect to the coil terminals of the Q-Meter a suitable coil having an inductance that will resonate to the desired frequency of measurement with a convenient tuning capacitance (see section 2A, page 8). Set the oscillator frequency to the desired value and the oscillator output to the 250 line on the Q range meter, and resonate the Q circuit by means of the Q tuning condenser. Call the condenser setting C_1 and the circuit Q, indicated on the Q voltmeter, Q_1. Call the oscillator frequency, f.

Connect the resistor to be measured in series with the coil in the Q circuit at the low potential coil terminal, and re-resonate the Q circuit, calling the new Q reading Q_2 and the condenser reading C_2.

The effective series resistance, R_s, of the resistor is:

$$R_s = \frac{1.59 \times 10^8 \left(\frac{C_1}{C_2} Q_1 - Q_2\right)}{f\, C_1\, Q_1\, Q_2} \qquad (23a)$$

If C_1 is greater than C_2 the effective reactance of the resistor is inductive and its effective series inductance, L_s, is:

$$L_s \doteq \frac{2.53 \times 10^{10} (C_1 - C_2)}{f^2\, C_1\, C_2} \qquad (25a)$$

of if the inductance, L_1, of the coil used in the Q circuit is known, the effective series inductance of the resistor may be calculated from:

$$L_s = L_1 \left(\frac{C_1 - C_2}{C_2}\right) \qquad (49)$$

If C_2 is greater than C_1 the effective reactance of the resistor is capacitive and its effective series capacitance, C_s, is:

$$C_s = \frac{C_1\, C_2}{(C_2 - C_1)} \qquad (26a)$$

When the effective reactance of a resistor is capacitive, it may often be more accurate to represent the resistor as a shunt or parallel combination of resistance and capacitance. If the effective parallel values of resistance and capacitance are desired, the Q of the resistor, Q_x, may be calculated from:

$$Q_x = \frac{(C_1 - C_2)\, Q_1\, Q_2}{C_1\, Q_1 - C_2\, Q_2} \qquad (22a)$$

and the effective series resistance and capacitance calculated from formulas (23a) and (26a) above, and these values used in formulas (18b) and (21b), page 5, to determine the effective parallel resistance, R_p, and capacitance, C_p. The general relations between series and parallel values are discussed in section 1, page 4.

7-C. HIGH RESISTANCE IN PARALLEL WITH Q CIRCUIT.

The same general procedure described in the preceding section 7-B should be followed when measuring resistors having a resistance value high enough to connect across the Q circuit, except that the resistor being measured should be connected to the condenser terminals of the Q-Meter instead of in series with the coil.

If Q_1 and C_1 are the Q and condenser readings at resonance without the resistor, and Q_2 and C_2 the readings with the resistor connected across the Q circuit, the effective parallel resistance, R_p, of the resistor is:

$$R_p = \frac{1.59 \times 10^8\, Q_1\, Q_2}{f\, C_1\, (Q_1 - Q_2)} \qquad (23b)$$

If the reactance of the resistor is capacitive, C_1 will be larger than C_2 and the effective parallel capacitance, C_p, of the resistor is:

$$C_p = C_1 - C_2 \qquad (26b)$$

If C_2 is larger than C_1 the reactance is inductive and the effective parallel inductance, L_p, may be calculated from:

$$L_p = \frac{2.53 \times 10^{10}}{f^2 \ (C_2 - C_1)} \qquad (25b)$$

When the effective reactance of a resistor is inductive it is sometimes more convenient to represent the resistor as a series combination of inductance and resistance, in which case the values of effective series resistance and inductance may be desired instead of the parallel values obtained from formulas (23b), (25b), and (26b) above.

If values of effective series resistance, inductance or capacitance are desired, the corresponding parallel values may be measured as described above and the Q of the resistor, Q_x, may be calculated from:

$$Q_x = \frac{(C_2 - C_1)\ Q_1\ Q_2}{C_1\ (Q_1 - Q_2)} \qquad (22b)$$

and the values thus obtained may be used in formulas (18a) to (21a), page 5, to determine the effective series values desired.

7-D. ANTI-RESONANT RESISTANCE OF A TUNED CIRCUIT.

This quantity, sometimes called the "dynamic resistance" is the resistance of a resonant LC circuit as measured at the terminals of the coil (or condenser). It is of interest when such a circuit is used as a coupling element in a vacuum tube amplifier having a high plate resistance, since the gain is proportional to the anti-resonant resistance. If the Q of a circuit is not too small, its anti-resonant resistance, R_d, is:

$$R_d = 6.28 \times 10^{-3}\ fLQ = \frac{1.59 \times 10^8\ Q}{f\ C} \qquad (50)$$

in which f is the resonant frequency and L, C, and Q are the circuit inductance, capacitance, and Q at resonance.

The anti-resonant resistance of a tuned circuit may be measured with the Q-Meter by treating the circuit as a high resistance and measuring its resistance in a manner similar to that described for resistors in the preceding section 7-C. In this case, however, after resonating the Q circuit of the Q-Meter without the circuit under test connected, and recording the values of Q circuit capacitance and Q as C_1 and Q_1, the circuit under test should be connected to the condenser terminals of the Q-Meter and the Q circuit re-resonated by *resonating the circuit under test* to the frequency of measurement, f, as indicated by a maximum deflection of the Q voltmeter. The new Q voltmeter reading may be called Q_2. The anti-resonant resistance, R_d, of the test circuit is then:

$$R_d = \frac{1.59 \times 10^8\ Q_1\ Q_2}{f\ C_1\ (Q_1 - Q_2)} \qquad (51)$$

PART TWO

OPERATING INSTRUCTIONS FOR THE TYPE 100-A Q-METER

The type 100-A Q-Meter is no longer being manufactured and has been replaced by the type 160-A Q-Meter. However, as many of the type 100-A Q-Meters are still in use, operating instructions are herein presented.

The detailed instructions for the installation, operation and maintenance of the type 160-A Q-Meter which are contained in the succeeding pages apply to the type 100-A Q-Meter with the following exceptions.

1. Power Supply Voltage. The proper line voltage and frequency is indicated on the nameplate on the top of the cabinet.
2. The ON-OFF switch is on the lower left side of the front panel.
3. Adjustment for Line Voltage. The HI-LO switch is in the rear of the cabinet.
4. Adjusting the Oscillator Output Voltage. This should be set to either the 250 or 500 line on the Q Range Meter, and the corresponding scale read on the Q Voltmeter.
5. Adjusting the Q Voltmeter. The zero adjust knob is directly below the Vernier Condenser Dial.
6. Replacement tubes. The same tubes are used except the rectifier, which is a type 80. For access, remove rear panel.
7. Thermocouple Unit. In the event of failure a replacement TC unit can be procured from BRC. This is identified as type 107-A replacement TC unit. The type and serial number of the Q-Meter must be stated when ordering a replacement TC unit.

The circuit diagram of the type 100-A Q-Meter is shown on the following page.

SCHEMATIC CIRCUIT DIAGRAM OF TYPE 100-A Q-METER

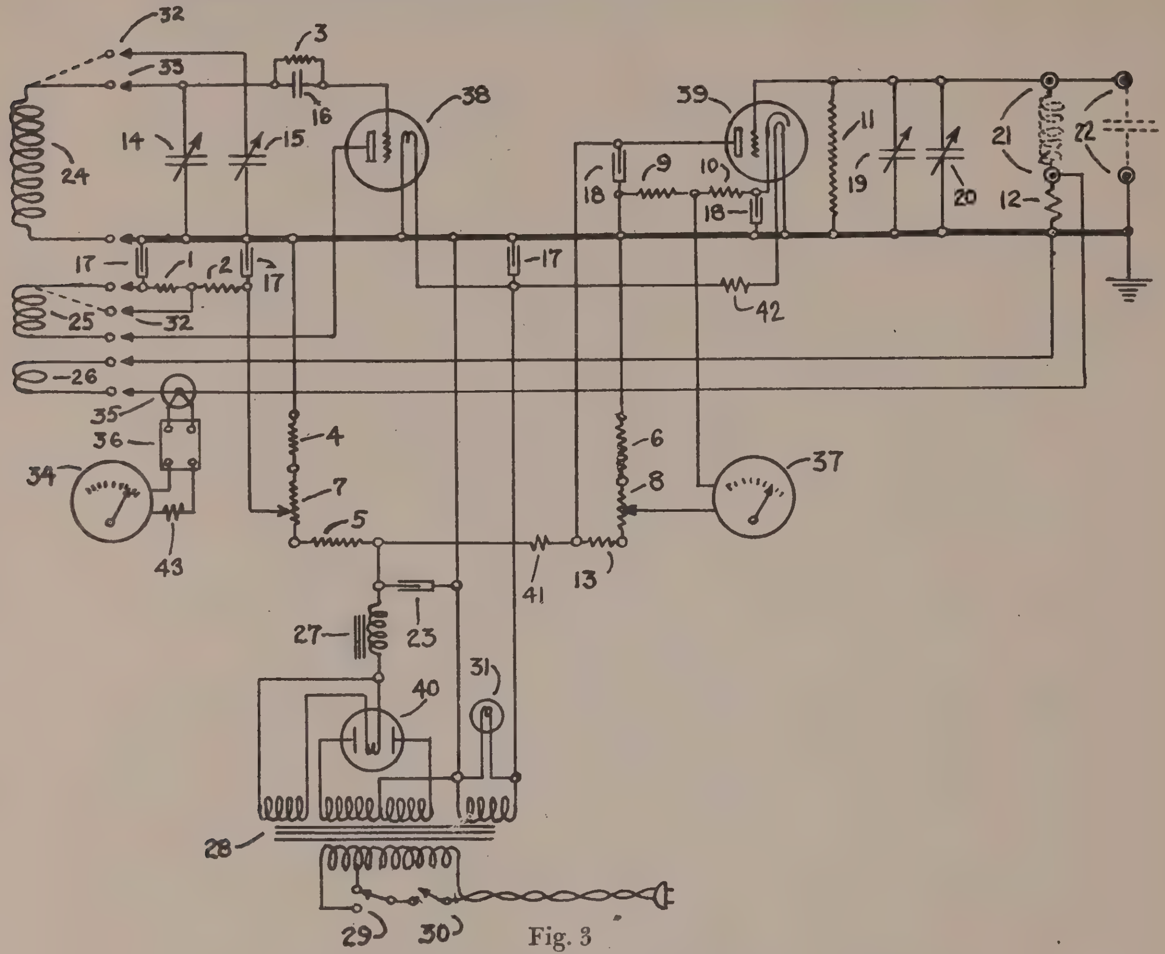


Fig. 3

CIRCUIT CONSTANTS AND DESCRIPTION OF PARTS

1	Fixed resistor	1,000 ohms.
2	Fixed resistor	200 ohms.
3	Fixed resistor	40,000 ohms.
4	Fixed resistor	3,000 ohms.
5	Fixed resistor	750 ohms.
6	Fixed resistor	70 ohms.
7	Potentiometer	8,000 ohms.
8	Potentiometer	200 ohms.
9	Fixed resistor	10,000 ohms.
10	Fixed resistor	25,000 ohms.
11	Fixed resistor	100 megohms.
12	Fixed resistor	.04 ohms.
13	Fixed resistor	50,000 ohms.
14	Osc. Tuning Condenser	(small).
15	Osc. Tuning Condenser	(large).
16	Fixed condenser	.0001 μf.
17	Fixed condenser	.003 μf.
18	Fixed condenser	.005 μf.
19	Q Tuning Condenser	(Main).
20	Q Tuning Condenser	(Vernier).
21	Terminals for test coils.	
22	Terminals for test condensers.	

23	Power filter condenser, 8 μf.	
24	Oscillator grid coil.	seven ranges
25	Oscillator plate coil.	seven ranges
26	Oscillator coupling coil.	seven ranges
27	Power filter choke.	
28	Power transformer.	
29	Line voltage switch.	
30	Line "ON"—"OFF" switch.	
31	Panel Lamp (Mazda 41, 2.5 volts).	
32	Oscillator range switch contacts.	
33	Oscillator range switch (see note).	
34	Oscillator output voltmeter.	
35	Oscillator output thermocouple.	
36	R. F. filter for osc. voltmeter.	
37	Q voltmeter.	
38	Oscillator tube (type 102-A).	
39	Q voltmeter tube (type 101-A or 101-B).	
40	Rectifier tube (type 80).	
41	Fixed resistor	1,000 ohms.
42	Fixed resistor	0.3 ohms.
43	Thermocouple calibrating resistor.	

NOTE: On some oscillator ranges the connections shown in dash lines are made.

OPERATING INSTRUCTIONS FOR THE TYPE 160-A Q-METER

DESCRIPTION

The principal units of this instrument are (1) an R. F. oscillator, (2) a measuring circuit, (3) means for coupling the oscillator to the measuring circuit, and (4) a power supply.

The R. F. oscillator is continuously variable between 50 KC and 75 MC and supplies a calibrated voltage to the measuring circuit. The coupling unit consists of a shielded transmission line terminating in a thermocouple and .04 ohm non-inductive resistor. The thermocouple measures the current which passes through the .04 ohm resistor and its associated meter is calibrated as a multiplier of the circuit Q indicated by the Q voltmeter. The measuring circuit consists of the main and vernier Q tuning condensers and a VT Voltmeter. When a coil is connected to the external coil terminals and resonance established between the oscillator and the measuring circuit the Q voltmeter (in conjunction with the "Multiply Q By" meter) indicates the Q of the circuit.

SHIELDED CABLE AND JACK.

A shielded cable (and jack) is supplied to permit operation between 1KC and 50 KC with an external oscillator. The output of the external oscillator must be variable and capable of supplying a maximum current of 0.5 amperes into an impedance of approximately 1 ohm. When an external oscillator is employed, it is necessary to disconnect the internal oscillator of the Q-Meter. This is accomplished by rotating the oscillator range switch (Item 5, page 23), to a position intermediate between any of the frequency range settings. Under these conditions the Q-Meter may be used for Q measurements, i.e., the Q Voltmeter reads circuit Q directly when the "Multiply Q By" Meter reads x1.

CAUTION:

The current from the external oscillator passes through a thermocouple system within the Q-Meter, the output of which is indicated on the "Multiply Q By" Meter, and care must be taken that this current does not exceed a value of 0.5 amperes which corresponds to an indication of x1 on the "Multiply Q By" Meter.

The shielded cable should be disconnected when the Q-Meter is used for Q measurements above 50 KC, i.e., without the external oscillator.

The shielded cable (or an unshielded cable) may be used for obtaining the internal oscillator output voltage for general laboratory work. The jack into which the shielded cable is plugged is connected within the Q-Meter as shown in the schematic drawing on page 27, Item No. 48. The oscillator output voltage at the jack is approximately 0.5 volts maximum. (This EMF is produced by the current of 0.5 amperes through the resistance of the heater of the thermocouple which is approximately 1 ohm.) This voltage may be read on the Q voltmeter by connecting the conductor within the shielded cable to the "HI" coil or condenser terminal. This voltage is substantially constant with frequency and inversely proportional to the indication of the "Multiply Q By" Meter up to the frequency region of 1 MC. Above 1 MC this voltage rises above 0.5 volts (for x1 on the "Multiply Q By" Meter) due to resonant conditions of the transmission line and the shielded cable. In certain frequency regions above 10 MC this voltage will vary between wide limits unless the free end of the shielded cable is terminated with a suitable impedance.

INSTALLATION

GROUND CONNECTION.

A ground connection should be made to the binding post on the rear of the cabinet for protection of the Q voltmeter.

POWER SUPPLY.

The power supply utilizes a dual-voltage transformer providing operation on either 115 or 230 volts, 50-60 cycles.

IMPORTANT:

Switch No. 30, page 23, must be set in the position corresponding to the voltage to be used. A lock is provided on this switch to prevent accidental changes in setting. (*)

ON-OFF SWITCH.

When the ON-OFF switch (No. 22 page 23) is turned ON, the panel lamp just above the switch should light and the oscillator output voltmeter should indicate some output. About a minute is required for the Q voltmeter tube to heat up; thus a short delay occurs before the Q voltmeter operates correctly.

PRECAUTION:

Before turning the Q-Meter ON, set the oscillator output control knob (No. 1, page 23) to mid-position to avoid a possible overload of the thermocouple.

HI-LO SWITCH.

This switch is located on the underside of the cabinet and should be set to the HI position for power line voltages slightly above normal, and to the LO position for voltages below normal. Normal voltage is either 110 or 220 volts, depending upon the setting of switch No. 30 page 23.

(*) Type 160-A Q-Meters of early manufacture are not provided with this dual-voltage switch.

OPERATION

The illustrations on page 23 will be helpful in identifying the various parts referred to in this and other sections. The figures in parentheses in the following description refer to the corresponding part on page 23.

CONTROLS.

There are four main controls, the oscillator range switch (5); the oscillator frequency control (3); the oscillator output voltage control (1); and the Q circuit tuning condensers, main (6) and vernier (10).

Q CIRCUIT TERMINALS.

Two terminals for coils (7) and two terminals for external condensers (8) are provided. The high potential and low potential terminals are indicated on the nameplate on the top of the Q-Meter.

SETTING THE OSCILLATOR FREQUENCY.

The desired frequency for a particular measurement may be obtained by selecting the range in which this frequency lies, by rotating the oscillator range switch (5) to this position and setting the oscillator tuning condenser (3) to the desired frequency.

The oscillator range switch dial (5) is engraved in eight frequency ranges, as follows:

50— 150 kilocycles	4.5—12.0 megacycles
150— 450 "	12.0—25.0 "
450—1500 "	25.0—50.0 "
1.5— 4.5 megacycles	50.0—75.0 "

The oscillator frequency dial (3) contains the calibrated scales corresponding to these same frequency ranges. The first three frequency ranges, which are calibrated in kilocycles, are engraved on the top half of this dial. The next four ranges, which are calibrated in megacycles, are engraved on the lower half of this dial. The eighth range, 50-75 mc, is engraved in RED on the top half of the dial.

ADJUSTING THE OSCILLATOR OUTPUT VOLTAGE.

The oscillator output voltage is indicated by the "Multiply Q By" meter. When the oscillator output is adjusted so that this meter reads x1 the Q voltmeter scale is to be read directly. For circuit Q's exceeding Q = 250 the oscillator output should be adjusted so

ILLUSTRATING THE IMPORTANT FEATURES IN THE OPERATION AND CONSTRUCTION OF THE TYPE 160-A Q-METER

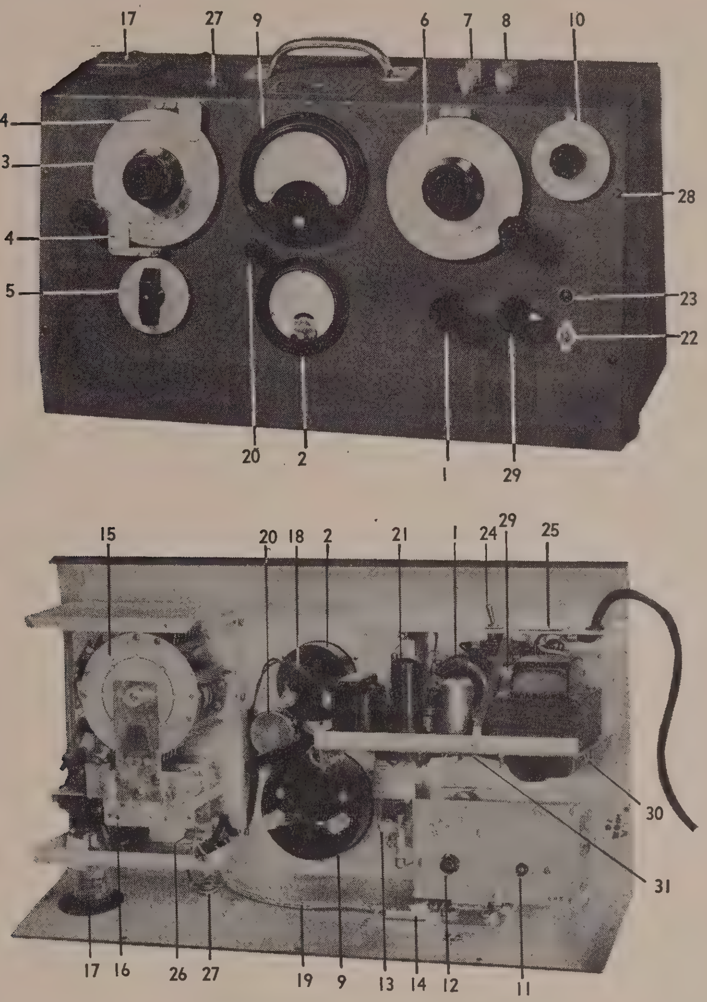


Fig. 4

DESCRIPTION OF PARTS

1 Oscillator Output Control.
2 Osc. Out. VM. (Mult. Q By Meter).
3 Oscillator Frequency Dial.
4 Oscillator Frequency Indicator.
5 Oscillator Range Switch.
6 Q Tuning Condenser Dial.
7 Coil Terminals.
8 Condenser Terminals
9 Q Voltmeter
10 Vernier Tuning Condenser Dial.
11 Vernier Tuning Condenser.
12 Q Tuning Condenser.
13 Q Voltmeter Tube.
14 Thermocouple Unit.
15 Oscillator Range Switch Assembly.
16 Oscillator Tuning Condenser.
17 Oscillator Tube.
18 Thermocouple Calibrating Resistor.
19 Oscillator Output Cable.
20 VTVM Zero Adjust.
21 Rectifier Tube.
22 ON—OFF Switch.
23 Pilot Light.
24 HI—LO Switch.
25 Power Unit Nameplate.
26 Thermocouple Filter.
27 Jack.
28 Panel Securing Screws.
29 Oscillator Output Control, Vernier.
30 Dual-Voltage Switch (115-230 volts).
31 VTVM Calibration Control.

that the "Multiply Q By" meter indicates a factor higher than x1, e.g., x1.1 or x1.2, etc. The Q voltmeter scale is then to be multiplied by this factor. For greatest accuracy the "Multiply Q By" meter should read as close to unity (i.e., x1) as is possible. The adjustment is made by means of the main control knob (1) and vernier control knob (29).

NOTE: In this method of indicating oscillator output voltage, the maximum oscillator output voltage to be employed exists when the "Multiply Q By" meter reads x1. For higher multiplying factors the oscillator output voltage is reduced, e.g., when the "Multiply Q By" meter is adjusted to read x2 the oscillator output voltage has been reduced to one half.

CAUTION: Care should be taken when changing the oscillator frequency to watch the oscillator output voltmeter and avoid overloading. This is a thermal meter system and excessive oscillator output may result in damage to the thermocouple.

ADJUSTING THE Q VOLTMETER.

The Q voltmeter (9) is adjusted to zero by means of the small knob directly below and to the left of the meter (see fig. 4).

For this adjustment a D.C. path between the two coil terminals must be provided, either by shorting the terminals with a jumper or connecting a coil to them. The Q circuit must be detuned from the oscillator frequency by rotating the Q tuning condenser through an appreciable range and observing that no change occurs in the Q voltmeter reading. The Q voltmeter should then be set to zero.

This adjustment should be made after the tubes have warmed up for about a minute and will then remain fairly constant. It is advisable, especially when accurate measurements with low Q circuits are being made, to check the zero setting of the meter occasionally by detuning the Q circuit.

The Q voltmeter should never be set to zero with the coil terminals open, since there is ordinarily an appreciable deflection of the meter due to the small grid current in the voltmeter tube with the coil terminals open. This deflection has no bearing on the accuracy of the meter as normally used to measure Q with a coil connected across the coil terminals.

PRECAUTION: Under certain circumstances extraneous voltages may be picked up by the exposed coil, from fields external to the Q-Meter. To determine if this is the case the oscillator should be definitely detuned from the circuit under measurement. The Q voltmeter should then read zero.

MEASUREMENT PROCEDURE – COILS.

A coil to be measured should be connected to the coil terminals (7)—page 23—provided on the Q-Meter, the oscillator frequency set to the desired frequency, and the coil resonated by means of the Q tuning condenser dial (6). Resonance is indicated by maximum deflection of the Q voltmeter (9). The Q voltmeter reading at resonance times the "Multiply Q By" factor indicates directly the Q of the measuring circuit. This is substantially the Q of the coil, except at the higher frequencies.

Since most coils in common use have a Q less than 250, it is advisable initially to set the oscillator output meter to the x1 position. If the Q of the test coil exceeds 250 the oscillator output voltage should be reduced, so that the "Multiply Q By" factor is increased.

The engineer will be able to estimate roughly the frequency at which a coil will resonate with a given tuning capacitance. Occasionally this may be difficult to estimate, particularly in the case of universal and multiple-section windings, in which case it becomes necessary to search for this resonance. The simplest method of doing this is to set the capacitance of the Q tuning condenser to about 100 or 200 $\mu\mu$f then to step the oscillator range-switch, sweeping each range with the oscillator condenser until resonance is indicated.

The oscillator output voltage is fairly uniform over the entire frequency range, except on the 50-75 mc range. Having obtained resonance, the oscillator output should be adjusted as above described.

The tuning capacitance required to resonate the coil may be read directly on the Q tuning condenser dial (6) in micro-microfarads. This capacitance is the total circuit capacitance of the measuring circuit in

the Q-Meter, including the voltmeter tube and terminals, but with nothing connected to the terminals.

This calibration obtains with the vernier condenser set at zero. With the vernier at some other position the total tuning capacitance is the sum of the readings of the main condenser dial and the vernier dial.

When leads or fixtures having appreciable capacitance are connected to the Q-Meter terminals and it is necessary to know the tuning capacitance accurately, the capacitance of these should be measured and added to the capacitance indicated on the dials.

MEASUREMENT PROCEDURE–OTHER COMPONENTS.

To measure components other than coils such as condensers, resistors, chokes, and insulating materials, it is necessary to provide a coil which will resonate to the frequency desired within the range of tuning capacitance of the Q-Meter (30 to 450 $\mu\mu$f) plus any additional capacitance of the components. This coil should be connected to the coil terminals of the Q-Meter and measurement of Q made as described above.

The measurement of such components requires two observations, one with the component disconnected and one with the component connected either in parallel with the Q circuit (to the condenser terminals (8)—page 23) or in series with the Q circuit. A series connection should be made in the coil circuit (between the coil and Q-Meter terminals) and provision made to maintain a continuous D.C. path through the coil and series component (by a resistor of not over 5 megohms shunting the component), if necessary.

Q, capacitance and frequency may be recorded for each observation which provides the necessary factors to calculate the quantity desired.

A more detailed description of the various measurements that may be made with the Q-Meter is given in Part I.

For many purposes comparison between similar components is as useful as measuring a specific factor, in which case it is unnecessary to make any calculations. The decrease in Q and change in tuning capacitance when the component is connected provide a rapid and accurate method of comparing a test component to a standard.

ACCURACY.

Q. The accuracy of the direct reading Q measurement is generally within 5% over the entire range of the Q-Meter except at the higher frequencies (above about 30 megacycles) where the accuracy may be somewhat less. In some cases at lower frequencies (with coils having a high distributed capacitance) the accuracy may be less. (See pages 2 to 3.)

Capacitance. The calibration of the Q tuning condenser is held to within plus or minus 1 $\mu\mu$f from 30 to 100 $\mu\mu$f and plus or minus 1% above 100 $\mu\mu$f. The dial calibration indicates the total circuit capacitance with the vernier set at zero, and with nothing connected to the Q-Meter terminals. The vernier condenser is accurate to 0.1 $\mu\mu$f.

Frequency. Accurate to about 1%. The average accuracy is generally better than 1%, especially near the low frequency end of each range.

COUPLING RESISTANCE.

In this instrument the oscillator output voltage is injected in the Q measuring circuit by means of a coupling resistance. This resistance unit is non-inductive and is of a very low order of resistance (0.04 ohm). In most cases this value of resistance is negligible, but the series resistance of resonant LC circuits may become very low at the higher frequencies, and the coupling resistance may then become an appreciable portion of the total circuit resistance and introduce an error.

This is unimportant in considerable design work where the main objective is to improve an existing coil or design the best component or circuit for a specific purpose, in which case the absolute Q is generally not wanted but a comparison between various components is highly desirable.

INTERNAL INDUCTANCE.

The internal inductance of the Q measuring circuit has been reduced to a low value by using short connections between the output binding posts and the Q tuning condenser. This inductance is less than .015 μhy at the binding posts.

MAINTENANCE

PARTS REQUIRING REPLACEMENT.

The only parts in the instrument that should require replacement are the dial lamp and the tubes consisting of:

1 Type 101-A or 101-B tube* for use in the vacuum tube voltmeter.
1 Type 102-A tube for use in the oscillator (tested type 45).
1 Type 5W4 rectifier tube.
1 Mazda 41, 2.5 volt Panel Indicator Lamp.

The type 101-A or 101-B tube is a specially selected and calibrated type 2A6 tube of commercial make. The type 102-A tube is a standard type 45 tube, tested for high frequency operation. Replacement tubes of these two types should be procured from Boonton Radio Corporation, Boonton, New Jersey, for best performance in the Q-Meter.

DEFECTIVE TUBES.

Normally the tubes used in the Q-Meter have a long useful life, although occasionally a defective tube may be encountered and must be replaced.

A defective type 102-A tube will usually be indicated if it is impossible to obtain full oscillator output voltage when the "HI-LO" voltage adjustment switch has been properly set. (See page 22.) It is also advisable to check the type 5W4 rectifier tube.

The type 101-A or 101-B tube (vacuum tube voltmeter) is a commercial 2A6 tube that has been carefully selected to meet the following requirements: (a) high input A.C. resistance (10 megohms minimum at 1000 kcs); (b) low grid current (0.05 microamperes) at normal operating voltages; (c) uniform plate current under normal operating voltages.

The vacuum tube voltmeter tube should be replaced if the Q voltmeter goes off scale when both high potential Q circuit terminals are disconnected from external circuits. (This condition does not indicate that the calibration of the Q voltmeter is in error but is due merely to grid current.) The calibration of the tube may be checked by measuring a standard coil of known Q.

The calibration of the Q voltmeter may be checked against a standard 60 cycle A.C. voltmeter by applying known voltages ranging from about 0.5 volt to 5.0 volts at the condenser terminals of the Q-Meter. Referring to the schematic circuit diagram (see page 27), the cathode-ground bypass condenser (18) must be temporarily increased to 8 μf for the 60-cycle calibration.

(*) These types are ordinarily interchangeable; they are identical except that the type 101-B has an input capacitance approximately 0.2 $\mu\mu$f greater than the type 101-A. The Q-condenser dial calibration will be changed by only 0.2 $\mu\mu$f if one type is substituted for the other.

REPLACEMENT OF TUBES.

The tubes and dial lamp are accessible when the front panel is removed from the rear cabinet, and the vent lid is removed from the top section of the front panel (see Pg. 23).

PRECAUTION: The instrument should be disconnected from the power line before the panel is removed to avoid the possibility of contact with the 250 "B" voltage or power line terminals within the instrument.

The lower illustration on page 23 shows the Q voltmeter tube (13), the oscillator tube (17), and the rectifier tube (21) in position. (NOTE: The shielding box cover over the oscillator range switch and coil assembly (15) has been removed in this illustration.)

The Q voltmeter and rectifier tubes are readily accessible. The oscillator tube may be removed after the vent lid on the cabinet top is removed.

All parts of the instrument are mounted on the front panel which may be removed from the rear cabinet after the securing screws on the sides and top have been removed (see Pg. 23).

ALIGNMENT OF DIALS.

If the dials or the indicators have been removed they may be correctly replaced in the following manner:

Oscillator. Turn the oscillator tuning condenser to the full maximum capacitance (low frequency) position, turn the dial until the zero line on the dial scale coincides with the vertical line of the top indicator, secure the dial to the shaft by means of the set screws and then adjust the top indicator more carefully to exact coincidence. The dial should be so positioned on the shaft of the condenser as to be close to the indicator to avoid parallax but should not scrape. The lower indicator should then be carefully adjusted to exact coincidence with the line at the 100 scale position of the dial.

Main Q Tuning Condenser. The procedure outlined above should be followed and the condenser

SCHEMATIC CIRCUIT DIAGRAM OF TYPE 160-A Q-METER

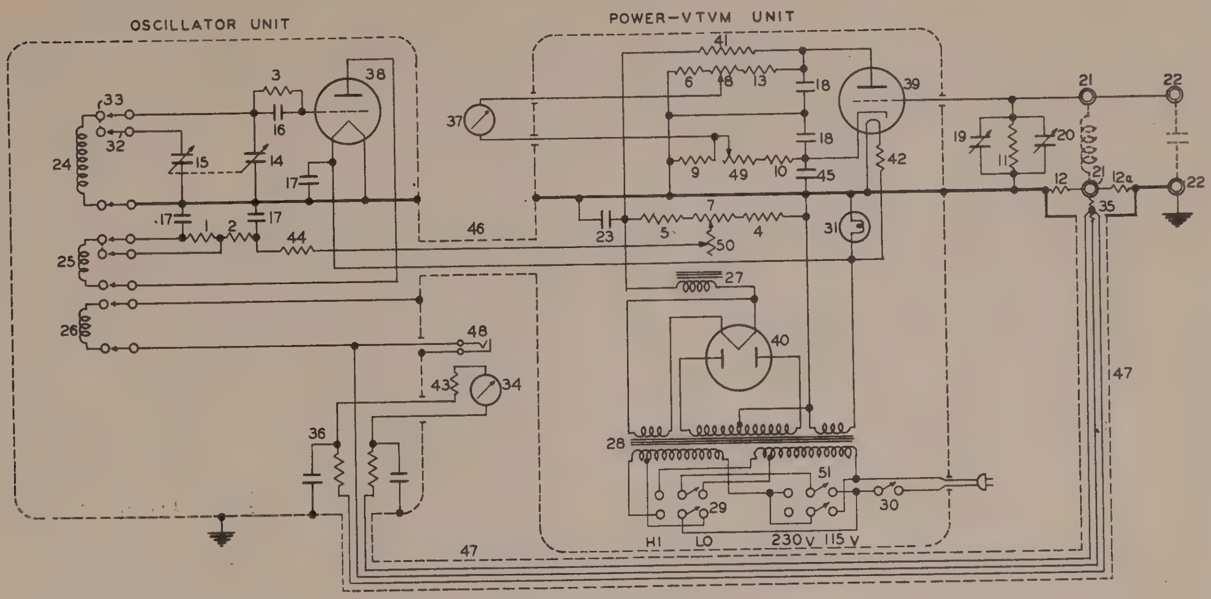


Fig. 5

CIRCUIT CONSTANTS AND DESCRIPTION OF PARTS

1	Fixed resistor	1,000 ohms.
2	Fixed resistor	200 ohms.
3	Fixed resistor	40,000 ohms.
4	Fixed resistor	2,500 ohms.
5	Fixed resistor	750 ohms.
6	Fixed resistor	200 ohms.
7	Potentiometer	8,000 ohms.
8	Potentiometer	200 ohms.
9	Fixed resistor	25,000 ohms.
10	Fixed resistor (1%)	24,000 ohms.
11	Fixed resistor	100 megohms.
12	12a (one unit) Fixed res.	.04 ohms.
13	Fixed resistor	50,000 ohms.
14	Osc. Tuning Condenser	(small).
15	Osc. Tuning Condenser	(large).
16	Fixed Condenser	.0001 μf.
17	Fixed Condenser	.003 μf.
18	Fixed Condenser	.005 μf.
19	Q Tuning Condenser	(Main).
20	Q Tuning Condenser	(Vernier).
21	Terminals for test coils.	
22	Terminals for test condensers.	
23	Power filter condenser,	8 μf.
24	Oscillator grid coil.	
25	Oscillator plate coil.	
26	Oscillator coupling coil.	
27	Power filter choke.	
28	Power transformer.	
29	"HI-LO" switch.	
30	Line "ON"—"OFF" switch.	
31	Panel Lamp (Mazda 41, 2.5 volts).	
32	Oscillator range switch contacts.	
33	Oscillator range switch (see note).	
34	Oscillator output voltmeter.	
35	Oscillator output thermocouple.	
36	R. F. filter for osc. voltmeter.	
37	Q Voltmeter.	
38	Oscillator tube (type 102-A).	
39	Q voltmeter tube (type 101-A or 101-B).	
40	Rectifier tube (type 5W4).	
41	Fixed resistor	1,000 ohms.
42	Fixed resistor	0.3 ohms.
43	Thermocouple calibrating resistor.	
44	Fixed resistor	100 ohms.
45	Fixed condenser	0.1 μf.
46	Shielded Cable.	
47	Shielded Cable.	
48	Jack.	
49	Potentiometer	3,000 ohms.
50	Potentiometer	1,000 ohms.
51	Dual-Voltage Switch (115-230 volts).	

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a. NOTE: On some oscillator ranges the connections shown in dash lines are made.

b. NOTE: The power-line plug utilizes two Type 3AG—½-amp. fuses.

turned to the maximum capacitance position so that the line which is beyond the capacitance calibration is coincident with the line on the indicator.

Oscillator Range Switch. This is keyed to the shaft in such a way that the only error possible is a 180 degree error and this may be readily avoided.

POWER UNIT VOLTAGES.

Referring to the schematic circuit diagram, page 27, the following voltages should obtain at the power unit.

With a line voltage of 115 volts, 60 cycles and line switch set on "HI" the A.C. voltage for the heaters should be 2.5 volts. The "B" voltage across the filter condenser (23) should be 260 volts.

THERMOCOUPLE.

If the thermocouple should be damaged or burned out it is highly advisable to return the Q-Meter to Boonton Radio Corporation, Boonton, New Jersey, for replacement of the thermocouple unit to insure highest accuracy of calibration. If this should be impossible, replacement thermocouple units will be supplied, calibrated to match any one Q-Meter. *It is necessary to state the type number and serial number of the Q-Meter in ordering a replacement thermocouple unit.*

METERS.

If a "Multiply Q By" meter should be damaged or defective it should be returned *together with the small calibrating resistor* connected to one side of the meter (see 18, page 23) for repair.

The serial number of the Q-Meter must always be stated when returning any meters for repair, or ordering replacements.

IF THE Q-METER SHOULD BECOME DEFECTIVE IN OPERATION DUE TO ANY CAUSE OTHER THAN TUBE FAILURE, IT IS ADVISABLE TO RETURN IT TO BOONTON RADIO CORPORATION, BOONTON, NEW JERSEY, FOR COMPLETE INSPECTION AND REPAIR.

SPECIFICATIONS

OSCILLATOR FREQUENCY RANGE: Continuously variable from 50 kilocycles to 75 megacycles in eight, self contained, ranges. (In conjunction with an external oscillator the frequency range of the type 160-A Q-Meter may be extended from 50 kilocycles to 1 kilocycle for coil measurements.)

OSCILLATOR FREQUENCY ACCURACY: Generally better than ±1%, except the 50-75 megacycle range which is approximately ±3%.

RANGE OF Q MEASUREMENTS: The Q voltmeter is calibrated directly in Q, 20-250. The "Multiply Q By" meter, which measures the oscillator voltage injected in the Q measuring circuit, is calibrated in tenths from x1 to x2, and also at x2.5. The reading of the Q voltmeter scale is to be multiplied by the setting of the "Multiply Q By" meter. Hence, the total range of circuit Q measurements is from 20-625. The Q's of condensers, dielectrics, etc., which may be as high as 5,000, are measured by placing these in parallel with the measuring circuit.

ACCURACY OF Q MEASUREMENTS: The accuracy of the direct reading measurement of circuit Q (for Q voltmeter readings between Q = 50 and Q = 250) is approximately 5% for all frequencies up to the region of 30 megacycles, and decreases with increasing frequency. Correction may be made for the error above 30 megacycles as it is principally a frequency effect. The accuracy of the measurement of condensers, dielectrics, etc., is generally better than 10% for Q's between 20 and 5,000, up to about 30 megacycles.

CAPACITANCE CALIBRATION RANGE: Main tuning condenser 30-450 $\mu\mu$f, calibrated in 1 $\mu\mu$f divisions from 30 to 100 $\mu\mu$f, and in 5 $\mu\mu$f divisions from 100 to 450 $\mu\mu$f. Vernier condenser, plus 3 $\mu\mu$f, zero, minus 3 $\mu\mu$f, calibrated in 0.1 $\mu\mu$f divisions.

ACCURACY OF CAPACITANCE CALIBRATION: Main tuning condenser, generally better than 1% or 1 $\mu\mu$f, whichever is the greater. Vernier tuning condenser ±0.1 $\mu\mu$f. The internal inductance of the tuning condenser at the binding posts is approximately .015 μhy.

VOLTMETER: The Q voltmeter is also calibrated in volts. A specially calibrated tube, type BRC 101-A or 101-B tube, is used. Replacements may be made without recalibration.

POWER SUPPLY: A self-contained dual-voltage transformer with change-over switch provides operation on either 105-120 volts, 50-60 cycles, or 210-240 volts, 50-60 cycles. Power consumption 50 watts.

TUBES: The Q-Meter is supplied complete with tubes which are (a) one type 45 tube, (b) one type BRC 101-A or 101-B tube, (c) one type 5W4 tube, and (d) one Mazda 41, 2.5 volt, panel lamp.

DIMENSIONS: Height 12.5", length 20", depth 8.5".

INSTRUCTION BOOK: Manual of r. f. measurements accompanies instrument.

OPERATING INSTRUCTIONS FOR TYPE 170-A Q-METER

In the 170-A, as in types 100-A and 160-A, a calibrated r. f. voltage derived from a self-contained oscillator is introduced into a series resonant circuit, the Q circuit. The calibrated oscillator voltage is coupled to the Q Measuring Circuit by a very small mutual inductance, thus eliminating the coupling resistor which is used in the lower-frequency Q-Meters, an important feature in view of the very small series resistance of tuned circuits in the upper frequency region. The oscillator output voltage is measured by means of a VT Voltmeter, which is calibrated as a multiplier of the Q voltmeter indication.

The Q circuit tuning condenser and its terminal posts have been made small to reduce the internal inductance and minimum capacitance. The condenser characteristic is linear over the major portion of its range; the dial is calibrated in micro-microfarads. In place of the vernier condenser used in types 100-A and 160-A Q-Meters, a worm drive is provided to give greater ease of tuning and to spread out the scale. The micrometer dial on the worm shaft is calibrated in 100 equal divisions, permitting changes of circuit capacitance of the order of .01 $\mu\mu$f to be determined. This feature permits the determination of circuit Q by the measurement of the width of the resonance curve (reactance variation method) and thus provides a means for checking the direct indication of the circuit Q as given by the Q voltmeter.

All calibrations are direct reading, thus retaining the advantages of speed and ease of operation which have proved so valuable through experience with this simplified method of Q measurement.

INSTALLATION AND OPERATION

POWER SUPPLY: The power supply utilizes a dual-voltage transformer providing operation on either 115 or 230 volts, 50-60 cycles.

IMPORTANT:

Switch No. 31, page 32, must be set in the position corresponding to the voltage to be used. A lock is provided on this switch to prevent accidental changes in setting.(*)

ON-OFF SWITCH: This switch is located on the lower left hand side on the front of the cabinet. A pilot light is also provided.

GROUND CONNECTION: To protect the Q circuit VTVM a ground connection should be made to the ground binding post located on the left side of the instrument.

CONTROLS: There are four main controls, namely the oscillator frequency range switch, the oscillator frequency dial, the oscillator output voltage (Q circuit injection voltage) control, and the Q circuit tuning condenser. See Fig. 6.

Q CIRCUIT TERMINALS: These are located on the right hand end of the top of the cabinet. The terminals for coils and condensers are indicated on the nameplate located on the top of the cabinet.

OSCILLATOR FREQUENCY RANGE: The settings of the oscillator frequency range switch and the oscillator frequency dial (both direct reading) determine the oscillator frequency.

OSCILLATOR OUTPUT VOLTAGE CONTROL: This is located on the lower right hand portion of the front panel. The oscillator output is indicated on the "Multiply Q By" meter.

ZERO ADJUSTMENT OF VT VOLTMETERS: There are two VT Voltmeters in the instrument, located on the left hand side of the panel. The Q Voltmeter is located on top; the "Multiply Q By" Voltmeter below. Both voltmeters should be checked for zero setting. The zero setting of the "Multiply Q By" Voltmeter may be made by reducing the oscillator output voltage to zero (turn control knob, item

(*) Type 170-A Q-Meters of early manufacture are not provided with this dual-voltage switch.

No. 9, Fig. 6, full left) and adjusting the small knob marked "X" located between the two meters until the "Multiply Q By" meter reads zero. The zero setting of the Q Voltmeter may be made by shorting the coil terminals of the Q Measuring Circuit and adjusting the small knob marked "Q" until the Q Voltmeter reads zero.

> **CAUTION:** Do not change factory adjustments shown in Fig. 6, items 22 and 24.

MEASUREMENT PROCEDURE: In general, the same measurement procedure as used with the type 160-A Q-Meter is employed. The direct indication of Q is to be multiplied by the indication of the "Multiply Q By" meter. The frequency of the oscillator and the tuning capacitance values are directly indicated on their dials. Measurement of L, C, Q, and R, at these high frequencies is more difficult than at lower frequencies. Some of the precautions to be observed are listed below.

PRECAUTIONS

1. Short Leads. Attention is especially called to the importance of using extremely short and wide (low inductance and low resistance) leads when connecting coils, condensers or other impedances to the terminals of the type 170-A Q-Meter for measurement at these high frequencies. As an example, a typical small molded mica condenser of 25 $\mu\mu$f nominal capacitance when connected to the condenser terminals with short ordinary wire leads showed a marked increase in effective capacitance at 200 mcs due to the inductance of the condenser and its leads. Replacing the wire leads with copper ribbon reduced the lead inductance and the apparent capacitance.

2. Coupling of unshielded coil to adjacent resonant structures. At high frequencies a surprising number of objects such as sections of electric light and power lines, power cords, coils, etc., may become resonant. If such objects are adjacent to an unshielded coil which is being measured in the Q-Meter they may affect the indicated Q of the coil (and its apparent inductance) in the frequency region of this resonance. This condition is indicated by a "kink" in an otherwise smooth curve of Q versus frequency. Under some conditions the indicated Q may be affected by the hands of the operator when placed close to or in contact with the instrument case, even though this is grounded in the conventional manner. Occasionally greater stability can be obtained by eliminating the ground connection. Engineers versed in VHF technique are acquainted with such phenomena. A stable condition can usually be obtained by re-arrangement of power line cables, removal of instrument from region of resonant structures, etc. In general, this condition is not present with shielded inductors.

3. Stability. The type 170-A Q-Meter has a self-contained "B" voltage regulator, however, an external line voltage regulator is recommended if the power line voltage is subject to fluctuation. The type 162-A Constant Voltage Transformer is suitable for this purpose.

A small amount of reaction on the oscillator output voltage when the Q measuring circuit is resonated to it is to be expected. This is usually of little importance in the direct measurement of the Q of a coil. However, in the measurement of the Q of a condenser it may be of importance since such measurements frequently involve the determination of small Δ Q values. Under these conditions the oscillator output should be readjusted to read x1 (or other multiple) when the measuring circuit is resonated to the oscillator.

In the type 170-A Q-Meter the oscillator output voltage is measured by a diode VTVM. This is the "Multiply Q By" meter on the front panel. The level of the oscillator output voltage will vary about 3-1 over the total frequency range of the instrument. As a result of the variation of output voltage level, the "Multiply Q By" meter may frequently be driven off scale. While it is desirable to avoid this, yet as this is a VTVM and not a thermocouple there is little danger of damaging the system. After the initial warm-up period the zero setting should be checked, thereafter it will be quite stable.

The Q VTVM is a small triode (type 955). This tube has been chosen as the Q VTVM tube in view of its low input capacitance and circuit loading. Only selected tubes are suitable for use in this application. The Q VTVM is less stable than the diode VTVM and its zero setting is quite sensitive to power line voltage fluctuations. This zero setting should be frequently checked to insure best operation.

4. Terminal Posts and Contact Resistance. These posts have been designed to reduce the capacitance and internal inductance of the Q Measuring Circuit to a minimum. Since the series resistance of coils used at high frequencies is usually less than one ohm, it is necessary that good contact be made between

the terminals of the coil under measurement and the terminal posts of the Q-Meter. Also since the inductance of such coils is usually well under one microhenry it is apparent that the terminals of the coils to be measured must fit the terminals of the Q-Meter with sufficient accuracy to permit their removal and subsequent replacement without appreciably changing their effective inductance.

MAINTENANCE

TUBES: Access to all tubes and the pilot light may be had by removing the panel from the cabinet and also removing the oscillator shield box. Refer to Fig. 6.

CAUTION:

To remove the Q VTVM tube (Item 30) the Q tuning condenser should be rotated until the plates are fully meshed. The Q VTVM tube and the oscillator output VTVM tube may be removed by pulling them directly out of their sockets.

Specially selected replacement VTVM tubes (Items 16 and 30) and oscillator tubes (Item 27) may be procured from Boonton Radio Corporation. Clean contacting surfaces on the tubes and sockets is imperative. The regulator and rectifier tubes and panel lamp are commercial types.

In the event of unsatisfactory performance of this instrument not curable by replacement of tubes, it should be returned to the factory for repair.

Q-CONDENSER WORM DRIVE: Should this become stiff through gumming of the lubricant the worm should be cleaned with a cloth or a pipe cleaner.

SPECIFICATIONS

OSCILLATOR FREQUENCY: 30 MC to 200 MC—Calibration accuracy plus or minus 1%.

RANGE OF Q MEASUREMENTS: The Q Voltmeter is calibrated directly in Q, from 80 to 300. The "Multiply Q By" Meter is calibrated from x1 to x4, hence, the total range of circuit Q measurements is from 80 to 1200.

ACCURACY OF Q MEASUREMENTS: The accuracy of the direct reading measurement of circuit Q (for Q Voltmeter readings between Q 100 and Q 300) is approximately plus or minus 10% up to 100 Mc and decreases with increasing frequency.

CAPACITANCE CALIBRATION OF Q CONDENSER: Range 11-60 $\mu\mu$f calibrated in unit $\mu\mu$f divisions. Accuracy: 1% or 0.5 $\mu\mu$f, whichever is greater. Micrometer dial calibrated in 100 divisions.

POWER SUPPLY: A self-contained dual-voltage transformer with change-over switch provides operation on either 110-120 volts, 50-60 cycles, or 220-240 volts, 50-60 cycles. Power consumption 50 watts.

DIMENSIONS: Height 10½", Length 17", Depth 8¾".

WEIGHT: 21 lbs.

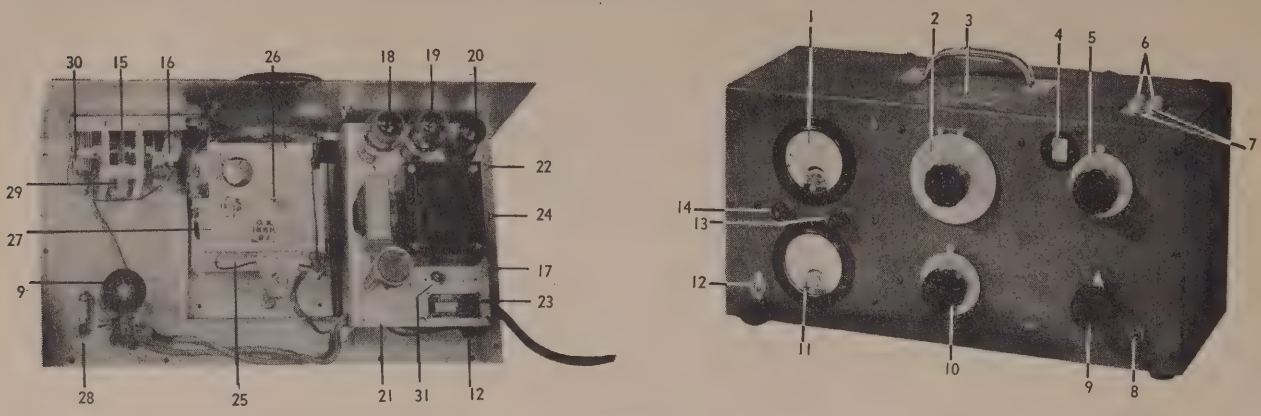


Fig. 6

DESCRIPTION OF PARTS OF THE TYPE 170-A Q-METER

1. Q Voltmeter
2. Oscillator Frequency Dial
3. Instrument nameplate
4. Q Tuning Condenser Main Dial
5. Q Tuning Condenser Vernier Dial
6. Coil Terminals
7. Condenser Terminals
8. Pilot Light
9. Oscillator Output Control
10. Oscillator Range Switch
11. "Multiply Q By" Meter
12. ON-OFF Switch
13. Zero Adjustment "X" Meter
14. Zero Adjust Q Voltmeter
15. Q Condenser Unit
16. Osc. Out. VTVM Tube (diode) type OS-VM-955
17. Injection Voltage Control
18. Power Unit Regulator Tube, Type VR-105-30
19. Power Unit Regulator Tube, Type VR-105-30
20. Rectifier Tube, Type 5W4
21. Power Supply Unit
22. Zero adjust limit control
23. Power Unit nameplate
24. Q Voltmeter calibration control
25. Oscillator Unit (with shield removed)
26. Threaded post for oscillator shield securing screw
27. Oscillator tube, Type 9002
28. Pilot Light, Mazda 47-6V
29. Q Condenser drive worm
30. Q Voltmeter tube (triode) Type Q-VM-955
31. Dual-Voltage Switch (115-230 volts).

REPLACEMENT OF Q-VOLTMETER TRIODE, ITEM 30, B.R.C. REPLACEMENT TYPE Q-VM-955

Should it become necessary to replace this tube, the following adjustments must be made to obtain proper operation with the new tube:

(1) After removing panel and replacing tube 30, allow 2 minutes for warm-up.

(2) Short-circuit the Q-condenser terminals, Item 7 above.

(3) Set the Q-voltmeter zero set knob (Item 14 above) at about the midpoint of its range.

(4) With a screwdriver, adjust the coarse zero set control, Item 22 above, to make Q-voltmeter, Item 1, read zero.

(5) Remove short-circuit from Q-condenser terminals and apply exactly 2.5 volts r. f. between these terminals. Adjust the Q-voltmeter calibrating control, Item 24 above, to make Q-voltmeter read 2.5 volts (Q=250). Re-check zero, by removing voltage, and re-check calibration.

IMPORTANT:

The bypassing of the Q-voltmeter is not sufficient to permit calibration by the use of an audio or power frequency. A radio frequency of ten megacycles or more must be used, together with a voltmeter or signal generator whose accuracy at this frequency is known. Short leads are imperative. The 170-A can itself be used to supply the calibrating voltage at its lowest frequency of 30 megacycles, if a voltmeter known to be correct at 30 mcs is connected across the Q measuring circuit which is resonated to this frequency.

SCHEMATIC CIRCUIT DIAGRAM OF TYPE 170-A Q-METER

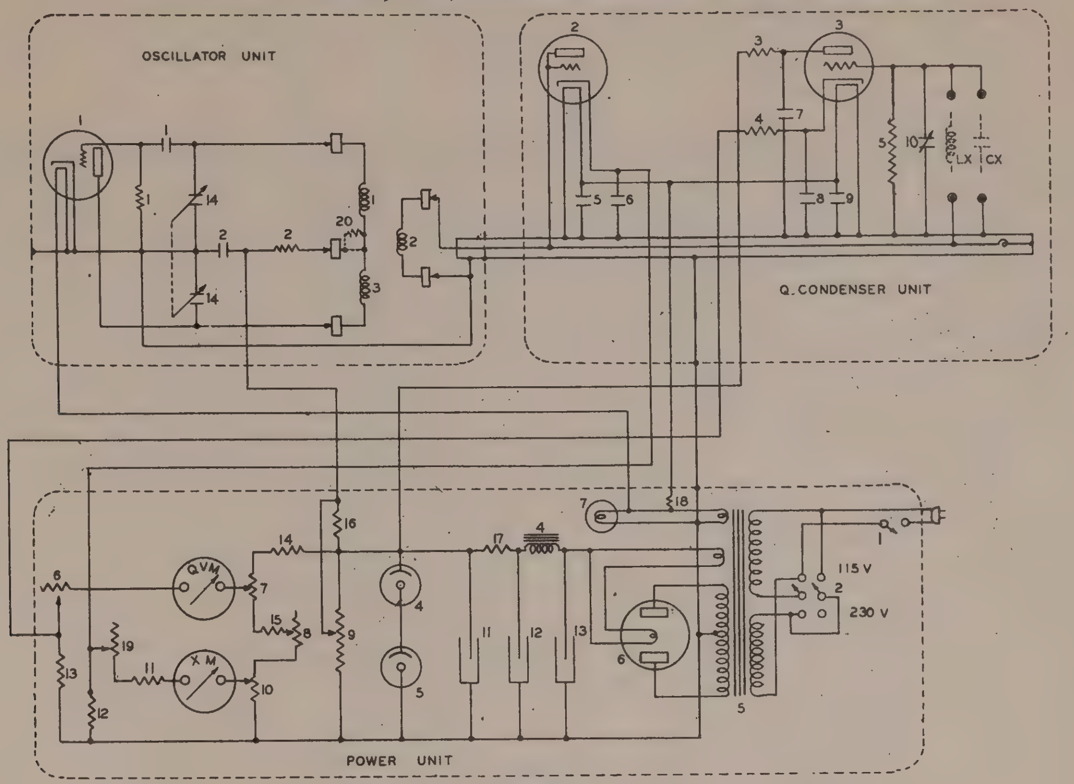


Fig. 7

CIRCUIT CONSTANTS AND DESCRIPTION OF PARTS

RESISTORS

1. 25000 Ω ½ w
2. 1000 Ω ½ w
3. 1000 Ω ½ w
4. 1000 Ω ½ w
5. 3 meg. 1/3 w
6. 7500 Ω Pot 3 w
7. 200 Ω Pot 3 w
8. 1000 Ω Pot 3 w
9. 20000 Ω Dual Pot 8 w
10. 200 Ω Pot 3 w
11. 20000 Ω ½ w
12. 25000 Ω ½ w
13. 25000 Ω ½ w
14. 40000 Ω 10 w
15. 1200 Ω ½ w
16. 25000 Ω 10 w
17. 2000 Ω 20 w
18. 0.8 Ω 2 w
19. 20000 Ω Pot 3 w
20. 50 Ω 1/3 w (†)

CONDENSERS

1. 20 μμf zero temp.
2. 250 μμf mica
5. 250 μμf mica
6. 250 μμf mica
7. 500 μμf mica
8. 500 μμf mica
9. 250 μμf mica
10. Q Tuning, Air
11. 4 μf. } Electrolytic
12. 4 μf. } Electrolytic
13. 4 μf. } Electrolytic
14. Osc. Tuning, Air

C_x. Test Condenser

SWITCHES

1. ON-OFF
2. Dual-Voltage (115-230 volts)

TUBES

1. Type 9002*
2. Type OS-VM-955*
3. Type Q-VM-955*
4. Type VR-105-30
5. Type VR-105-30
6. Type 5 W 4
7. Mazda 47-(6V)

INDUCTORS

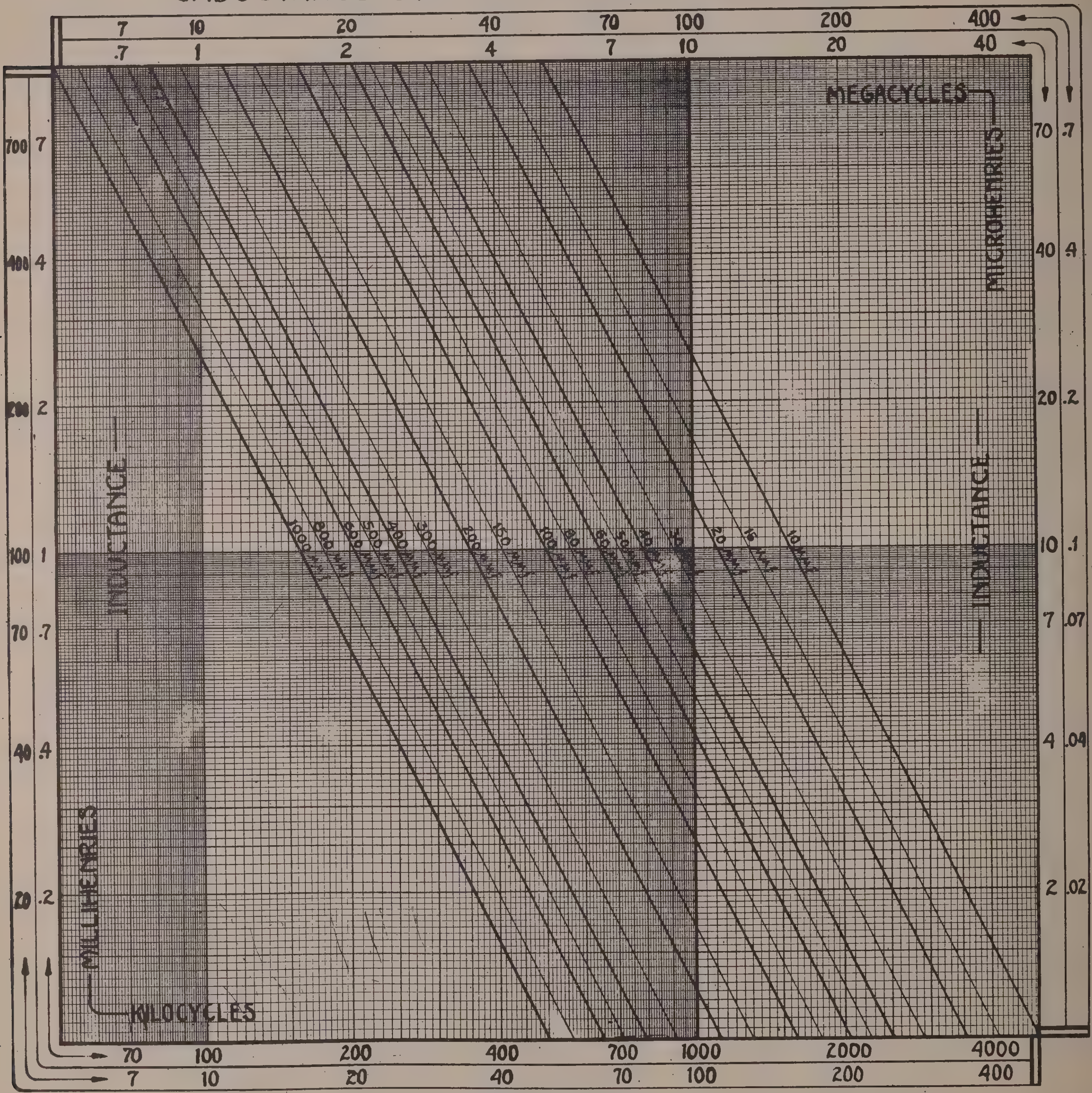
1. Osc. Grid
2. Osc. Coupling
3. Osc. Plate
4. Pwr. Choke
5. Pwr. Transf.

L_x. Test Coil

*Selected and Calibrated, Replacements procurable from Boonton Radio Corp.
(†) Not used on 60-120 Mc range.

NOTE: The power-line plug utilizes two Type 3AG—¾-amp. fuses.

INDUCTANCE-CAPACITANCE-FREQUENCY CHART



FREQUENCY